NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ASSEMBLY AND COMMISSIONING OF NAVAL POSTGRADUATE SCHOOL GAS GUN FOR IMPACT STUDIES

by

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December 2009

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13. ABSTRACT (maximum 200 words)

The Naval Postgraduate School (NPS) commissioned a gas gun for shock wave studies on 9th October 2009, by performing the first experiment. The gas gun is the key element of the NPS Shock Wave Research Program within the Physics Department, where well-characterized planar impacts are essential for obtaining high quality data, to characterize a solid material.

This gas gun was designed by SANDIA NATIONAL LABORATORIES; NPS spent twelve months fabricating the components of the gas gun and six months assembling them.

The gas gun launches three-inch projectiles at velocities up to 0.5 km/s, creating high pressure and temperature states that can be used to characterize the fundamental responses of relevant materials to dynamic loading. The projectile is launched from a "wrap around" gas breech where helium gas is pressurized to relatively low pressure. Upon impact, the speed of the projectile and the flatness of the impact is measured, via a stepped circular pin array circuit. With these data the gun's performance was generated for future uses.

The next stage of development for the gas gun is to integrate a Velocity Interferometer System for Any Reflector (VISAR).

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ASSEMBLY AND COMMISSIONING OF NAVAL POSTGRADUATE SCHOOL GAS GUN FOR IMPACT STUDIES

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ABSTRACT

The Naval Postgraduate School (NPS) commissioned a gas gun for shock wave studies on 9 October 2009, by performing the first experiment. The gas gun is the key element of NPS Shock Wave Research Program within the Physics Department, where well-characterized planar impacts are essential for obtaining high-quality data, to characterize a solid material. This first experiment was very successful and returned key data on the quality of the impact conditions created.

This gas gun was designed by SANDIA NATIONAL LABORATORIES, and the NPS spent twelve months fabricating the components of the gas gun and six months assembling them.

The gas gun launches three-inch projectiles, at velocities up to 0.5 km/s, creating high pressure and temperature states that can be used to characterize the fundamental responses of relevant materials to dynamic loading. The projectile is launched from a “wrap around” gas breech where helium gas is pressurized to relatively low pressure. This gas is used to accelerate the projectile down a three-meter barrel. Upon impact, the speed of the projectile and the flatness of the impact is measured via a stepped, circular pin array circuit.

The next stage of development for the gas gun is to integrate a Velocity Interferometer System for Any Reflector (VISAR). The VISAR sees all the waves that flow through the target plate because of the impact. This is a key diagnostic for determining material properties under dynamic loading conditions.

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I. INTRODUCTION

A. MOTIVATION

This thesis describes the assembly and commissioning of a single-stage gas gun in support of the Naval Postgraduate School (NPS) shock wave research program, where planar impact shock waves are used for characterizing properties of materials of interest. As the principal tool used for this kind of research at NPS, it is critical to understand the details of impact conditions produced by this facility. In particular, very planar impacts are required, and the performance of the gun also needs to be understood in detail. This gun allows destructive testing to be done in a very controlled way, but it is very important that the gun itself be robust, and not easily damaged. This all adds up to a requirement that the gun be reliable and well-characterized.

B. OBJECTIVE

The objective of this thesis is to determine whether the gas gun is capable of firing a projectile onto a test material under very controlled conditions for planar impact studies. To achieve the objective, the gas gun needed to be assembled and commissioned via firing the first shot, where the velocity of the projectile and the tilt of the impact are determined. These are key parameters for use of the gas gun for controlled shock wave experiments.

To better characterize the properties of materials of interest, the integration of a Velocity Interferometer System for Any Reflector (VISAR) to the gas gun is also required. This is outside the scope of this thesis and is left as future work. VISAR systems allow accurate time-resolved data to be obtained, which in turn allows many dynamic material properties to be determined.

C. PLANAR IMPACT EXPERIMENTS TO DETERMINE CHARACTERISTICS OF MATERIALS [5]

Planar impact experiments are often used to determine the dynamic characteristics of a material. Properties that may be obtained using such experiments include determination of the shock Hugoniot, strength in compression, strength in tension, and the location of phase transitions. To achieve highly accurate data, very planar impacts are required.

Guns are normally used to launch projectiles under a controlled environment onto a target plate to induce an impact at a velocity (Ud). (Refer to Figure 1. Illustration of Impact). After launch, the projectile moves at a velocity of Ud towards a stationary target plate. Upon impact, there is a discontinuity in particle velocity between the projectile and the target. Thus, shock waves are developed to relieve this discontinuity in particle velocity, and a similar discontinuity in pressure. Shock waves are produced in both the projectile and target plate, and propagate away from the impact surface at the appropriate shock velocities. For symmetric impact where the target and flyer are made of the same material, there is one common shock velocity. If the target and flyer are made from different materials, the target and flyer will have different shock velocities. The velocity of the shock wave generated in the target plate is measured by using time of arrival pins or a Velocity Interferometer System for Any Reflector (VISAR), or a combination.

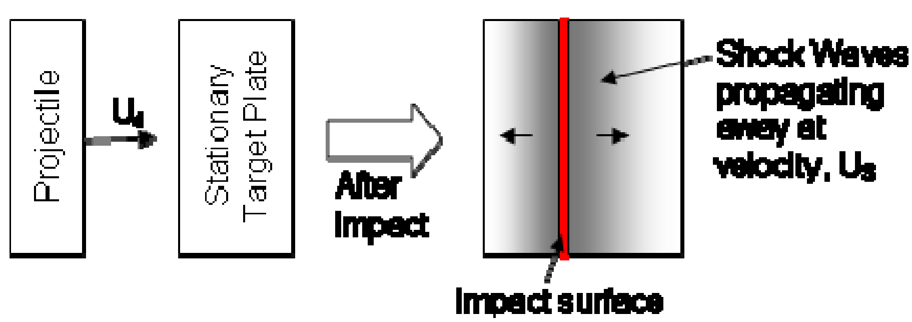

Figure 1. Illustration of Impact (Same material for Projectile and Target Plate) [After 5]

To determine the fundamental shock response of the target material, a plot of shock wave velocity (U_s) versus particle velocity (u_p) is required. Assuming that both the projectile and target plate are made of the same material, the particle velocity (U_p) is equal to $U_d/2$. This is shown in the Pressure (P) versus Particle Velocity (u_p) diagram, where the Hugoniot for the shock in the target plate increases to the right and the Hugoniot for the shock in the projectile is a mirror image of the target plate and it is towards the left. The intersection of the right-going Hugoniot and the left-going Hugoniot, is known as the common P-u_p state. This is the state between the shock waves in the flyer and the target, where particle velocity (u_p) is equal to $U_d/2$. (Refer to Figure 2. Illustration of P-up Diagram (Same Material for Projectile and Target Plate) [After 5])

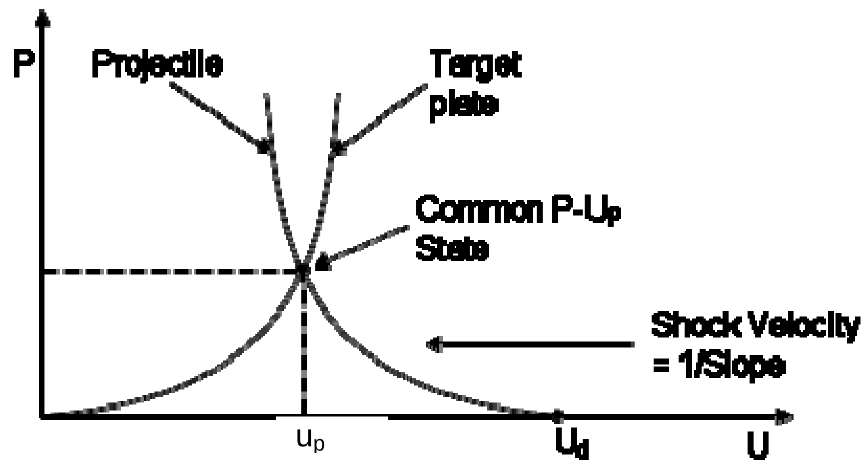

Figure 2. Illustration of P-u_p Diagram (Same Material for Projectile and Target Plate) [After 5]

To plot the shock wave velocity (U_s) versus particle velocity (u_p), several experiments are required, using various projectile velocities (U_d). The Y-intercept of the linear U_s-u_p line is the bulk wave speed (C_b) and S is the slope of the linear U_s-u_p line. (Refer to Figure 3. Illustration of Shock Wave Velocity (Us) versus Particle Velocity (up)).

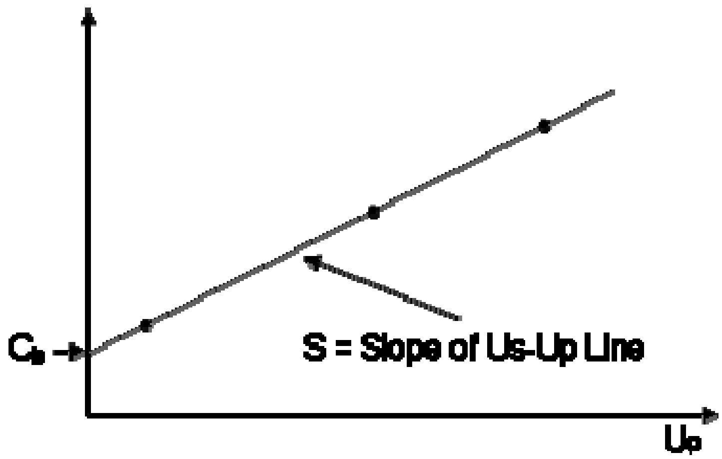

Figure 3. Illustration of Shock Wave Velocity (Us) versus Particle Velocity (u_p) [After 5]

The shock Hugoniot as shown above is the most fundamental measure of how a material responds to dynamic compression using shock waves. For that reason, it is important to measure shock and particle velocities with accuracy and precision. To do this requires, at a very fundamental level, exceptionally flat impacts. Projectile tilts of between 1 and 3 millirandians (mrad) are necessary to ensure that conditions of uniaxial strain in the target are achieved. For this reason, attaining very flat impact conditions was a main thrust of the work described in this thesis.

D. GAS GUN

Generally, for flyer-plate impact studies, guns are used to accelerate a projectile through a barrel to generate the required impact onto a target under controlled conditions. Three types of guns are generally available for use in impact studies. These are single-stage propellant-driven guns, single-stage gas-driven guns and two-stage propellant and gas-driven guns.

Figure 4. Single-stage Gun

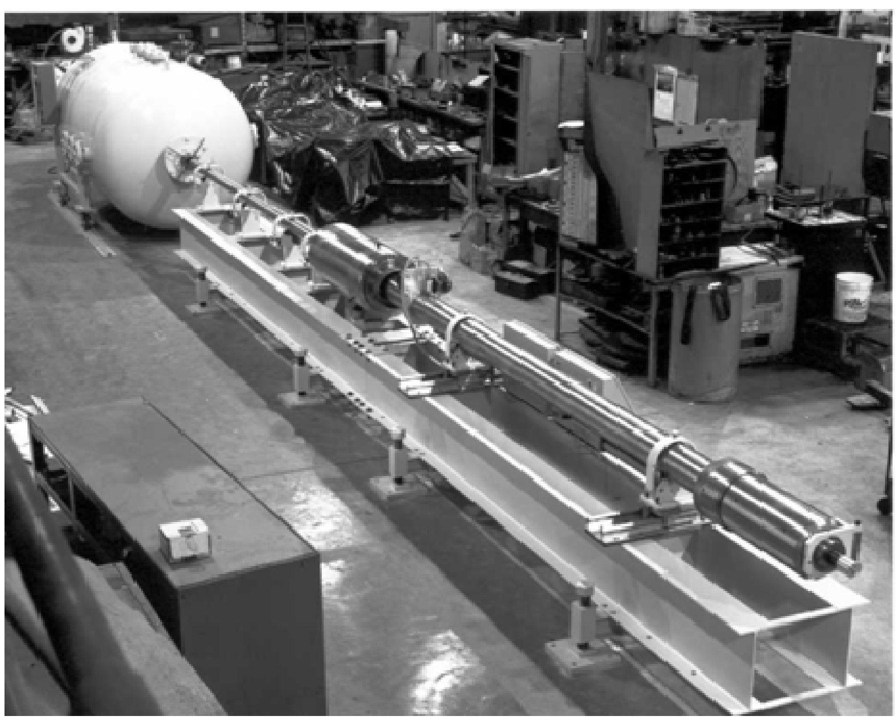

Figure 5. Propellant and Gas-driven Gas Gun [1]

Generally, these three types of guns work on the same concept where rapid expansion of a gas behind the projectile accelerates it up to the required speed towards the target, which is mounted in a vacuum chamber where the environment is controlled. This results in an impact that yields quantifiable data on the characteristics of the target material.

The basic design of both kinds of single-stage guns (whether gas- or propellant-driven) are quite similar. They are made up of a breech, a barrel, and a diagnostic tank. In addition, there is a catch tank which is used to slow down and catch experimental debris well after data has been obtained. The main difference between gas and propellant guns is in the design of the breech, where different methods are used to generate the expanding gas that is used to drive the projectile.

For the propellant-driven gun, a burning (deflagrating) propellant is used to generate the rapidly expanding gas within the breech, which is initially sealed by the projectile. Upon ignition of the propellant, the expanding gas accelerates the projectile towards the target. For propellant-driven guns the speed of the projectile ranges from 0.3 to 2.7 kilometers per second (km/s) and the projectiles range from 0.17 to 8 inch diameter in size [1].

Generally, the propellant-driven gun has the most space-efficient design as the length of the barrel is shorter for a given projectile velocity. Propellant-driven guns are known to be slightly less suitable for precision impact studies, as the gun is subjected to high recoil forces generated from the detonation of the propellant. However, they are still widely used to collect accurate fundamental data. To maintain the performance of the gun, extra effort is required to maintain the cleanliness of the gun, due to the residue from the burnt propellant.

For gas-driven guns, pressurized gas is used to generate the expanding gas within the breech. Normally high-pressure helium or hydrogen is used to charge the breech. Hydrogen is the best gas for high performance, but safety considerations cause its use to be limited.

Currently, there are two breech designs commonly used in gas guns. In the first breech design, the “wrap around” type, the projectile is used as a seal to prevent the expansion of the pressurized gas within the gas chamber in the breech. To launch the projectile an external force must be applied to the projectile, to move it towards the target, thus breaking the seal. Once the seal between the pressurized chamber and the rear surface of the projectile is open, the pressurized gas is allowed to expand behind the projectile, thus accelerating it down the barrel.

For this type of breech design, a negative pressure (vacuum) on the rear surface of the projectile is required to keep it in place. This vacuum is required to balance the vacuum that exists on the front of the projectile, which is open to the evacuated barrel and experimental chamber. Movement of the projectile during the charging of the gas chamber would result in premature launch of the projectile.

As for the second breech design, two diaphragms are used between two pressure chambers and the rear surface of the projectile. One chamber has a pressure P and the other has a pressure of P/2. Each diaphragm is rated to burst at a pressure between P/2 and P. To launch the projectile, the P/2 chamber is decreased in pressure until the diaphragm between it and the P chamber ruptures, which results in the acceleration of the projectile. This design is called a double-diaphragm design for obvious reasons.

Generally, single-stage gas-driven guns with a wrap around breech design are used for low-velocity projectile impact studies, and the double-diaphragm design is used to obtain higher velocities. The double-diaphragm breech can be pressurized up to a maximum pressure of about 15000 pounds per square inch (psi), thus achieving projectile velocities ranging from 0.002 to 1.6 km/s. Compared to the propellant-driven gun, the gas-driven gun operates within a less-constrained safety envelope [1].

The operating concept of the two-stage propellant- and gas-driven gun is based upon the extension of the single-stage gas driven gun, where burning propellant is used to dynamically create pressurized gas within the gas chamber in the breech. The design of the barrel and the catch tank is quite similar to that of single-stage guns. The main difference is in the charging /compression of gas within the breech assembly.

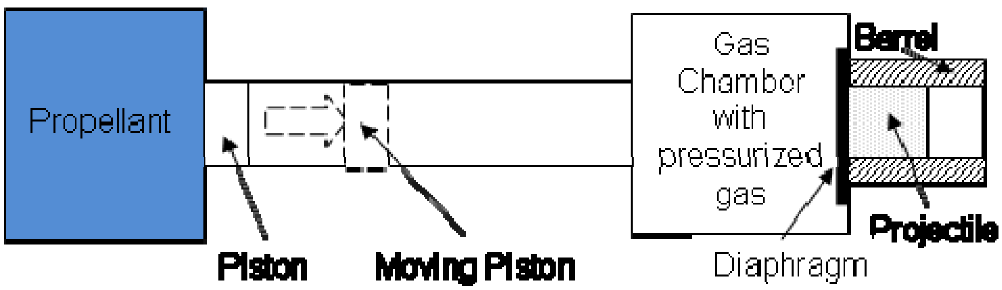

Figure 6. Illustration of Two Stage Breech

Two-stage gas guns are used to obtain the highest projectile velocities. In this design, propellant is used in the first stage to compress either hydrogen or helium gas with a piston. When the pressure reaches a certain value, a diaphragm ruptures and allows the very high-pressure gas to flow behind the projectile in the second stage. Typically, the launch tube is much smaller in diameter than the first stage (pump) tube to obtain a mechanical advantage. Using this technique, projectile velocities ranging from 1.5 to 8km/s can be obtained. (Refer to Figure 6. Illustration of Two Stage Breech) [1], [2]. Note that some moderate-performance two-stage guns use a compressed gas breech as the energy source for the first stage, rather than a propellant. These guns are easier to use and have less contamination from propellant residue, and so are used for moderate-velocity applications.

Generally, two-stage propellant- and gas-driven guns are designed to launch projectiles of bore diameter more than 0.17 inch [1]. Because this type of gun is capable of very high velocities, it is commonly used to simulate the impact caused by meteorites.

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II. BACKGROUND

NPS has fabricated and assembled a gas gun that was designed by SANDIA NATIONAL LABORATORIES (SNL). The NPS was awarded the rights to fabricate this gas gun for impact studies, but with the provision that the drawings not be further disseminated. Therefore, detailed design details will not be given in this thesis. The design of this gas gun is proven to be effective, as SNL has conducted a few hundred tests using a similar gas gun.

The gas gun Project started in June 2008 with the acquisition and fabrication of parts and components. As some of the main components used in this gas gun are customized, special fabrication expertise was required, thus increasing the acquisition process to about one year. In June 2009, all the major components were fabricated and delivered to the NPS, allowing the assembly of the gas gun.

The gas gun has five main systems:

a. Main Gun Assembly–made up of the gun parts

b. Pressure System–2 sub-system (High and Low Pressure)

c. Vacuum System

d. Control System–suite of gauges to monitor the pressure and vacuum of the system and a panel of switches to control the solenoid valves

e. Diagnostic System

A. MAIN GAS GUN ASSEMBLY

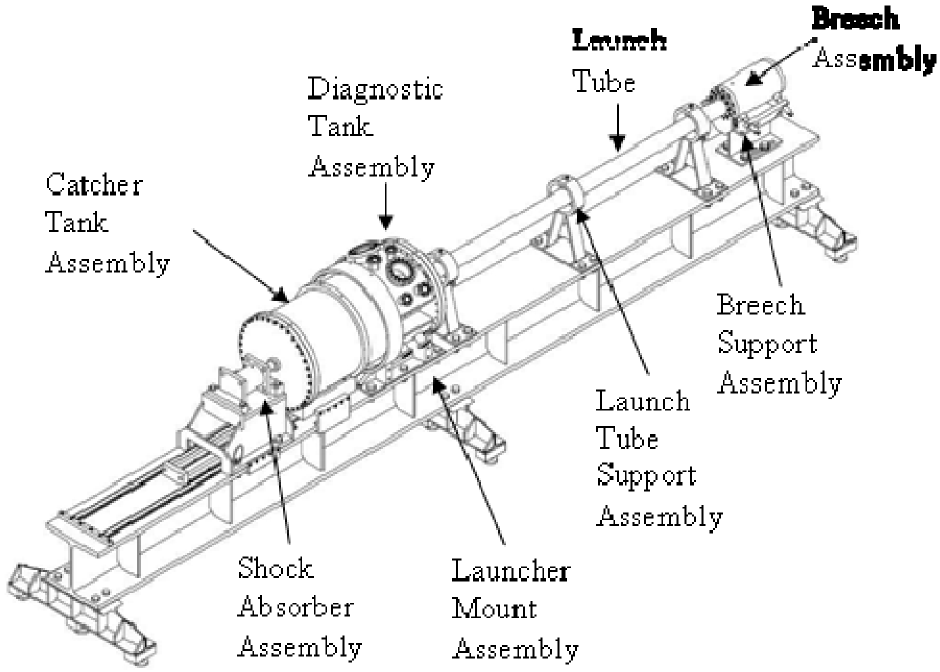

Figure 7. Main Gas Gun Assembly [After 5]

The main gas gun assembly comprises of eight sub-assemblies. The assemblies are mounted onto the launcher mount assembly, where it acts as a base and a horizontal datum. The eight sub-assemblies of the gas gun are:

a. Breech Assembly

b. Breech Support Assembly

c. Launch Tube

d. Launch Tube Support Assembly

e. Diagnostic Tank Assembly

f. Catcher Tank Assembly

g. Shock Absorber Assembly

h. Launcher Mount Assembly

Further details for the sub-assemblies are listed in their respective sections of the chapter (Refer to Figure 7. Main Gas Gun Assembly [After 5]).

1. Launcher Mount Assembly

The launcher mount assembly consists of the main rail mount, which rests on the three main rail mount support feet. The main rail mount has a machined upper surface, where all the sub-assemblies of the main gas gun assembly are mounted. There are nine leveling feet used to ensure that the machined surface is level. (Refer to Figure 8. Launcher Mount Assembly [After 5]).

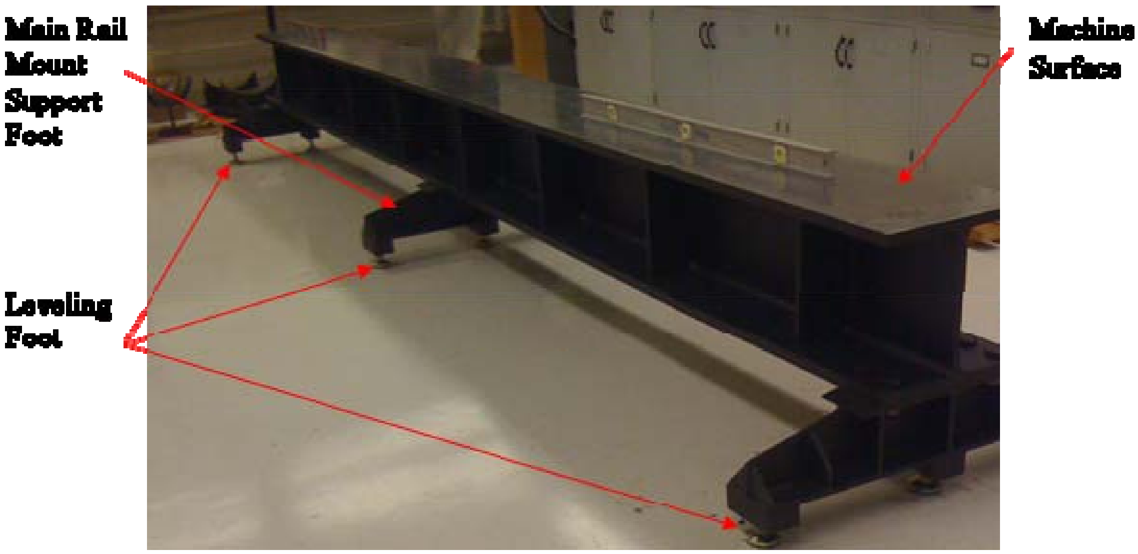

Figure 8. Launcher Mount Assembly [After 5]

2. Breech Assembly

A "wrap around" design is used for the breech assembly of this gas gun. For the "wrap around" design, the projectile has rubber O-ring seals on both ends to seal the ports in the launch tube to the high-pressure chamber of the breech.

During the vacuum stage of gun operation, the diagnostic tank, catcher behind the projectile are together evacuated down to pressure less than 100 milliTorr (mTorr). It is very important that the volume behind the projectile is subjected to the vacuum to ensure that the projectile remains in position, sealing

the port between the launch tube and the high-pressure chamber. If the projectile were to move forward during this process, the gun could fire prematurely.

For firing of the gas gun, a small amount of low-pressure gas is injected into the projectile cavity area to push the projectile past the ports in the launch tube, thus allowing the high-pressure gas from the breech chamber to flow in through the ports to accelerate the projectile. (Refer to Figure 9. Breech Assembly [After 5]).

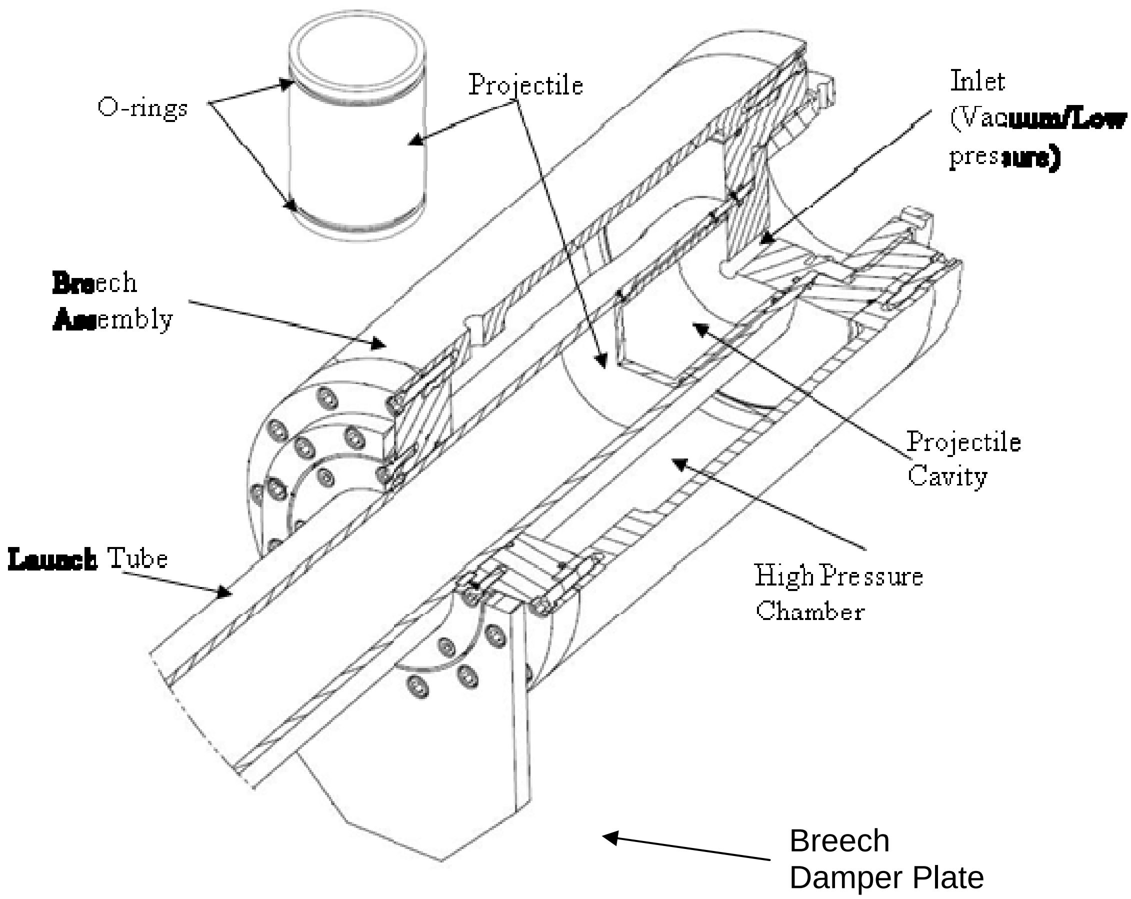

Figure 9. Breech Assembly [After 5]

3. Breech Support Assembly

The breech support assembly is used to support the weight of the breech assembly, and to align it properly to the barrel. The ends of the adjustable breech supports are made of Delrin material, which supports and facilitates the movement of the breech assembly.

An adjustable shock absorber has been integrated onto the breech support assembly to absorb any barrel/breech recoil shock induced by the launch of the projectile. (Refer to Figure 10. Breech Support Assembly [After 5].)

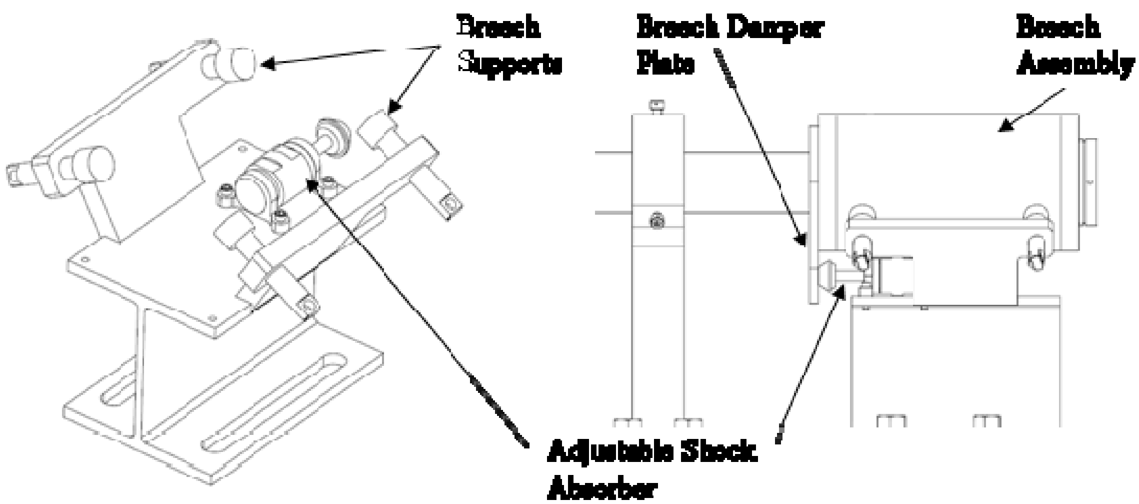

Figure 10. Breech Support Assembly [After 5]

4. Launch Tube

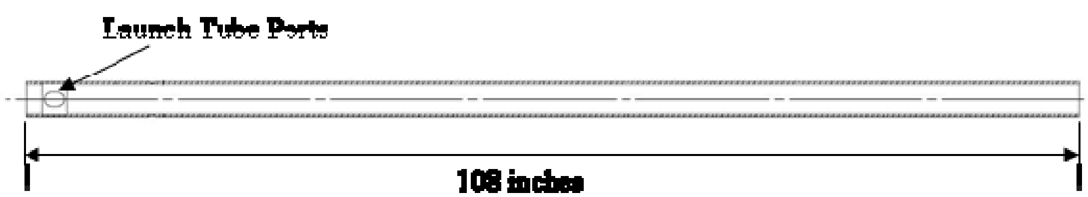

Figure 11. Launch Tube [After 5]

The launch tube is machined from steel, Honed I.D. 1.0 D.D.M. 1026, Mechanical Tubing, ASTM A513. The length of the launch tube is 108 inches, with an inner diameter of 3 inches and an outer diameter of 3.499 inches. The launch tube has three ports positioned 60 degrees apart. These launch tube ports allow high-pressure gas from the high-pressure chamber to flow behind the projectile once it moves past the launch tube ports (Refer to Figure 11. Launch Tube [After 5]).

5. Launch Tube Support Assembly

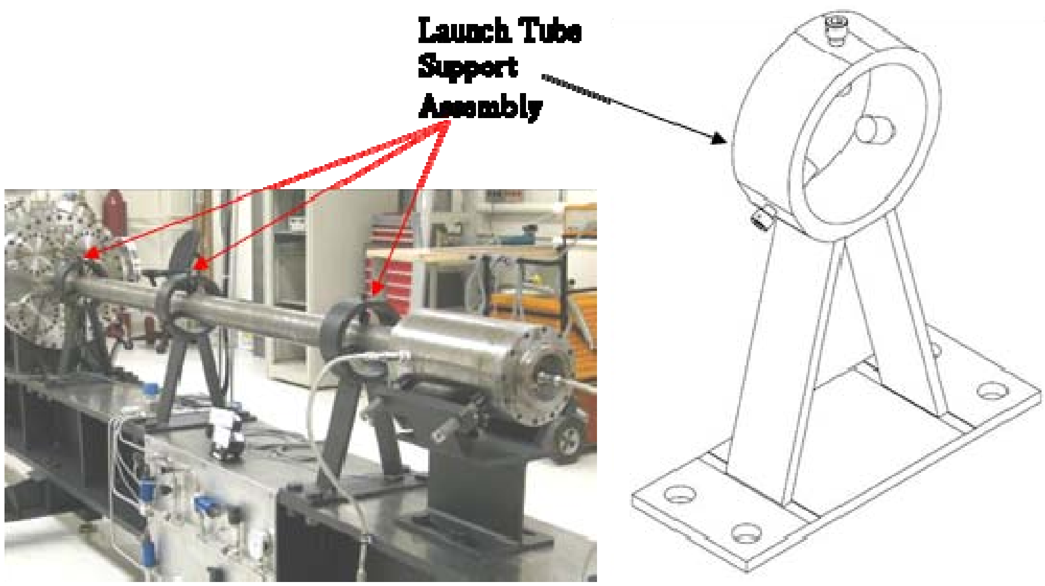

Figure 12. Launch Tube Support Assembly [After 5]

Three launch tube support assemblies hold the launch tube in position. The launch tube support assemblies are placed 37.63 inches apart (Refer to Figure 12. Launch Tube Support Assembly [After 5]).

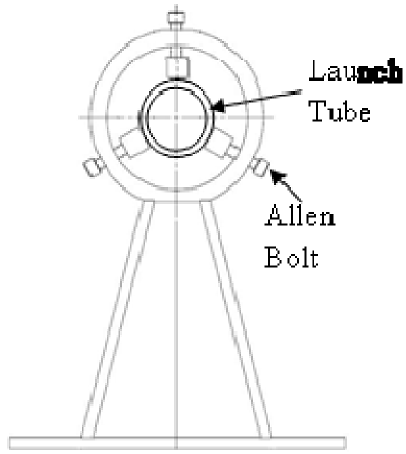

Figure 13. Launch Tube Support Assembly with Launch Tube [After 5]

The launch tube support assembly is designed to fulfill three main functions:

1. The launch tube support assembly is to hold the launch tube in place after it is aligned to be normal to the plane of the target plate.
2. The three allen bolts on the launch tube support assembly are used when aligning the launch tube to the target plate. (Refer to Figure 13. Launch Tube Support Assembly with Launch Tube [After 5].)

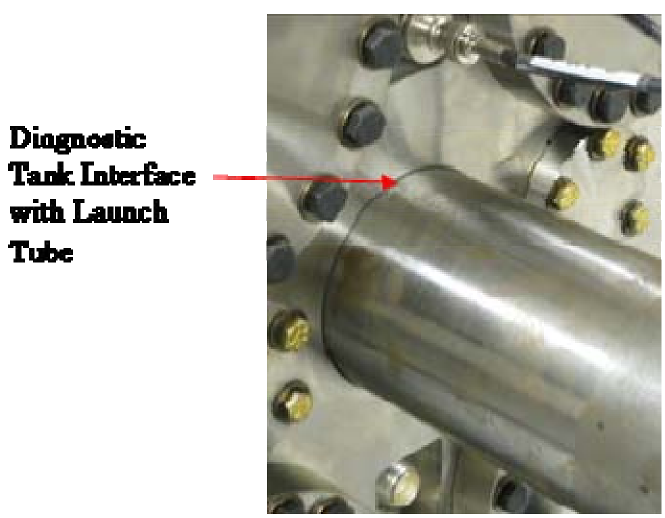

Figure 14. Interface between Launch Tube and Diagnostic Plate

3. The launch tube support assembly supports the weight of the launch tube to ensure that the rubber O-ring seal used at the launch tube and diagnostic tank interface is not subjected to uneven compression caused by the weight of the launch tube. The launch tube support assembly adjusts to compress this rubber seal evenly (Refer to Figure 14. Interface between Launch Tube and Diagnostic Plate).

6. Diagnostic Tank

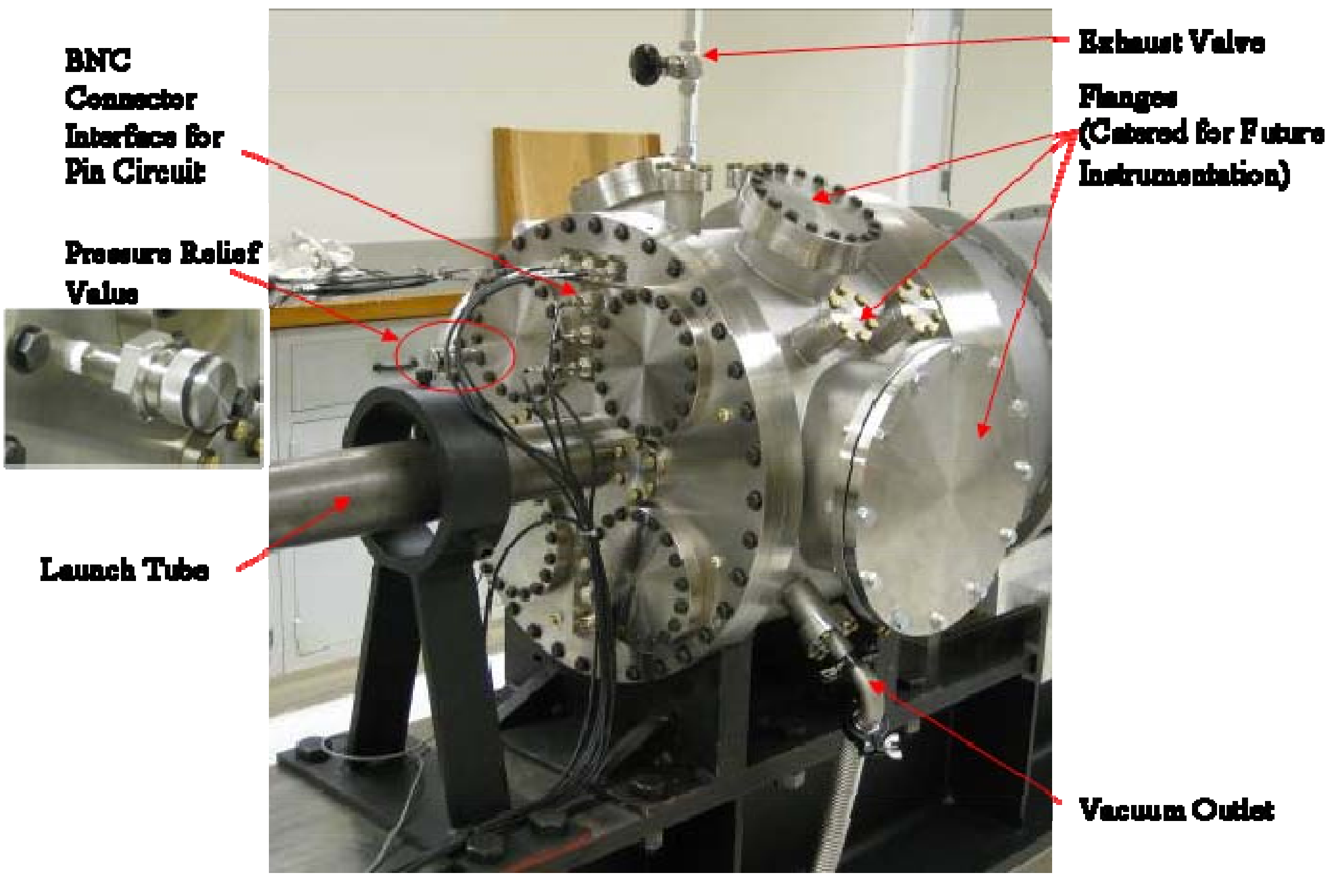

Figure 15. Diagnostic Tank

The diagnostic tank functions as a target holder, where diagnostic instruments are set up to collect data from the collision of the projectile with the target. The tank is equipped with several coaxial vacuum-tight feedthroughs.

These are used to allow signals to pass from inside to outside the diagnostic chamber. For initial tests, these are used to record pin diagnostic outputs. Several RC pin circuits are used to measure the velocity and the flatness of the impact between the projectile and the target. This will be discussed in more detail below (Refer to Figure 15. Diagnostic Tank).

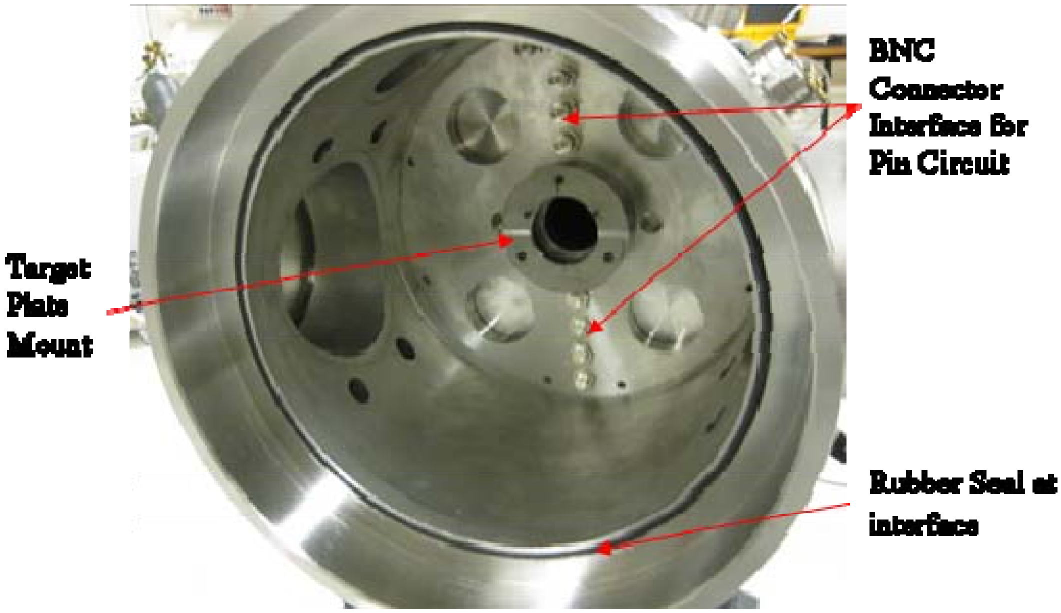

Figure 16.   Internal of Diagnostic Tank

The diagnostic tank is designed with removable port flanges of numerous diameters to allow for future diagnostic instrument integration. These flanges eliminate the need to modify the Diagnostic Tank.

The diagnostic tank is evacuated to less than 100 mTorr, to eliminate the possibility of a cushion of gas forming in front of the projectile during its flight down the barrel. The tank is also fitted with two pressure-relief valves. These valves are used to release any pressure build-up after the projectile impacts the target. This is used because eventually all of the helium gas used in the breech ends up distributed throughout the gun after the experiment (Refer to Figure 16. Internal of Diagnostic Tank).

7. Catcher Tank Assembly

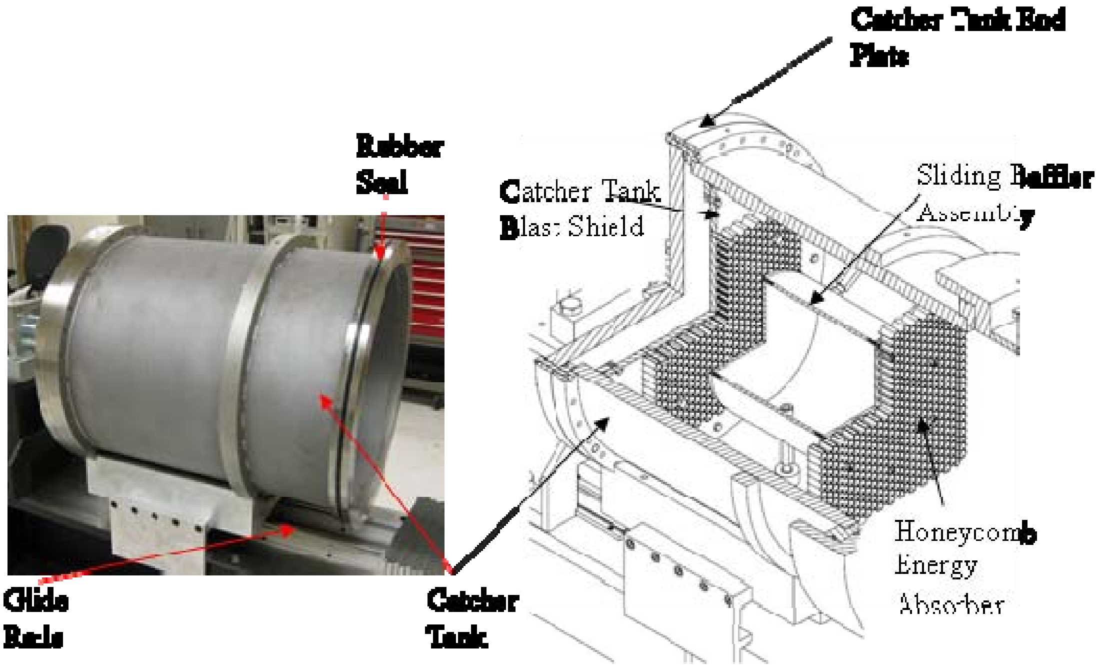

Figure 17. Catcher tank Assembly [After 5]

The catcher tank assembly is used to catch the target plate and projectile debris after impact. The catcher tank assembly consists of a sliding baffle assembly and catcher tank blast shield (Refer to Figure 17. Catcher tank Assembly [After 5]).

Both ends of the sliding baffle assembly are mounted with several honeycomb energy absorber pieces. The honeycomb energy absorber deforms upon impact from both the target plate and projectile impacts, thus absorbing energy and reducing the impact to the catcher tank (Refer to Figure 18. Sliding Baffler Assembly [After 5]).

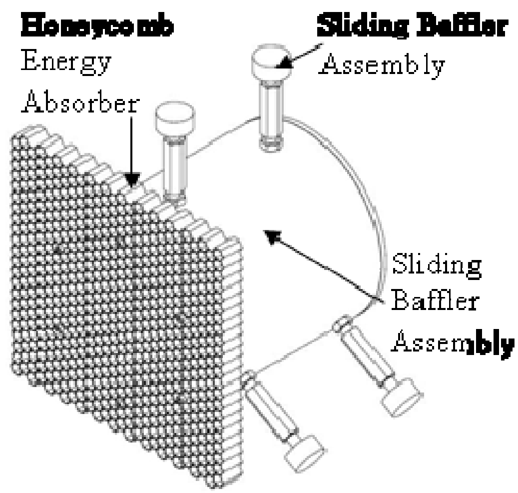

Figure 18. Sliding Baffler Assembly [After 5]

The catcher tank is mounted with a catcher tank blast shield to withstand the residual velocity of the sliding baffler assembly. This also acts a shield to prevent the target plate, projectile and sliding baffler assembly from direct impact onto the catcher tank end plate and helps to prevent damage to the seal between the catcher tank and the end plate interface.

8. Shock Absorber Mount Assembly

The shock absorber mount assembly is designed to absorb the catcher tank recoil via an air charged piston-type shock absorber. Due to the weight of the shock absorber mount assembly, rails are used to facilitate the translation of the shock absorber mount assembly between two positions of the main gun assembly; the preparation position and the launch position. At the launch position, two spring plungers and two fasteners are used to secure the shock absorber mount assembly where it is subjected to recoil from the catcher tank assembly (Refer to Figure 19. Shock Absorber Mount Assembly).

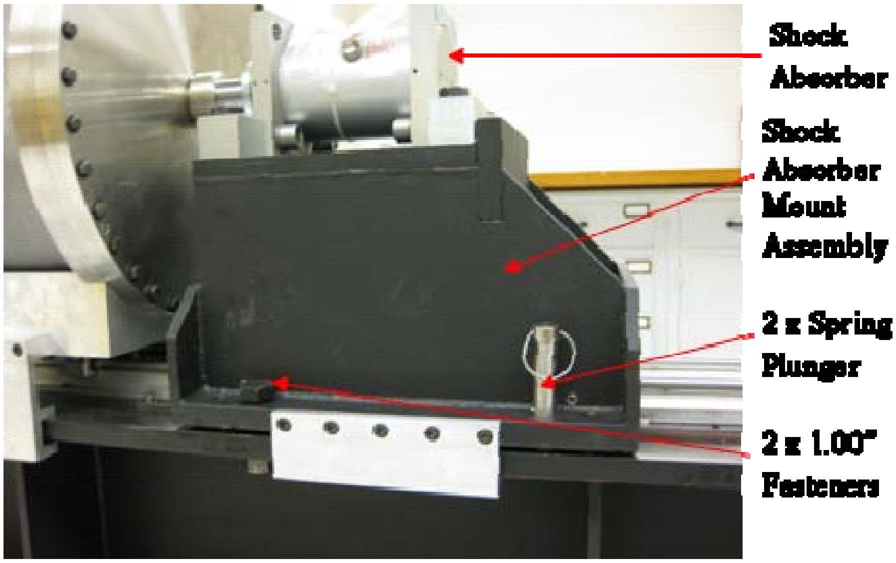

Figure 19. Shock Absorber Mount Assembly

B. PRESSURE SYSTEM

The pressure system is made up of two sub-systems, one for high pressure and one for low pressure (Refer to Figure 21. Circuit Diagram for combined Vacuum and Pressure). Note that high pressure in this system is still not high in an absolute sense. The maximum pressure used in the breech assembly is 1200 psi, which is significantly below the pressure in the commercial gas cylinders used. The pressure system is connected using 3/8-inch steel tubing and steel connectors so that the system is able to easily withstand the operating pressure.

The system is pressurized by a 6000 psi helium cylinder. The pressure from the helium cylinder is regulated down to the maximum operating pressure of 1200 psi via two regulators connected in tandem. The first regulator is a 6000 psi regulator and it is connected directly to the helium cylinder. The output pressure from this regulator is set to 1200 psi. The second regulator is a 4000 psi regulator and it is connected after the first regulator. The second regulator functions as a

safety feature. This tandem layout eliminates the possibility of accidentally charging the breech to a pressure greater than 1200 psi (Refer to Figure 20. View of System Pressure Supply).

The system is connected to a system pressure-relief valve. The pressure relief valve is connected after the tandem regulators. The 1500 to 2500 psi pressure-relief valve functions as a safety controller for the entire system, and will open automatically in the event of a system overpressure.

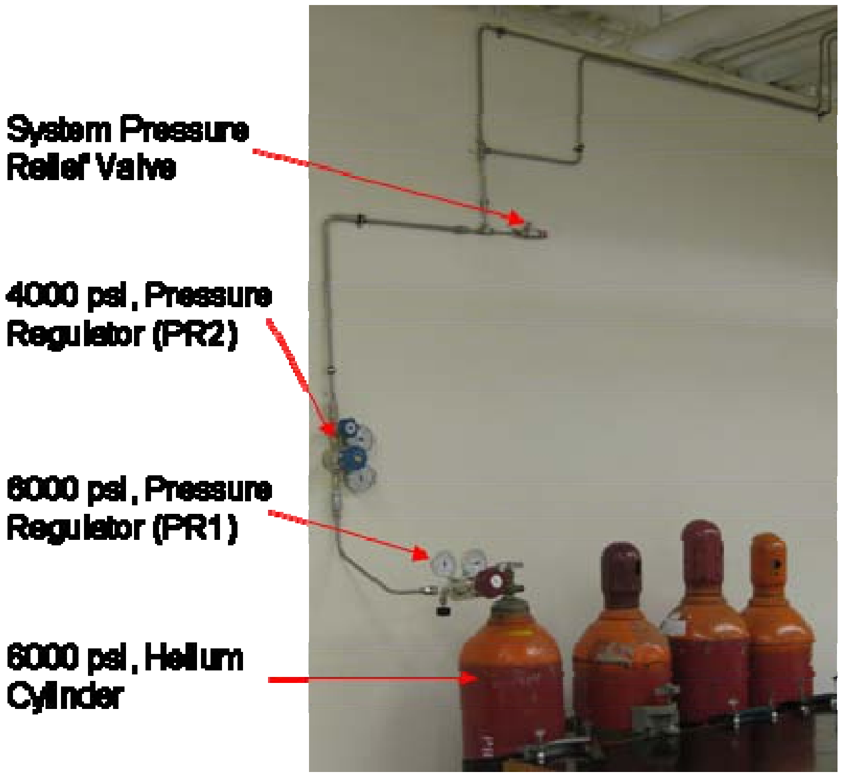

Figure 20. View of System Pressure Supply

1. High-pressure System

The high-pressure system operates up to 1200 psi and it is used for charging the breech to the required launch pressure.

An exhaust line has been integrated into the high-pressure system. This is used to discharge the pressure within the system. The exhaust line also contains a fine metering valve, which allows the release of pressure in the breech in a controlled manner (Refer to Figure 21. Circuit Diagram for Combined Vacuum and Pressure System).

2. Low-pressure System

The function of the low-pressure system is to push the projectile past the ports on the launch tube to initiate the launch of the projectile. The low-pressure system is regulated down to 120 psi via a 4000 psi regulator. A 150–350 psi pressure-relief valve is integrated into the system just before the low-pressure line integrates with the vacuum line. This functions as a safety control for the low-pressure system.

C. VACUUM SYSTEM

The vacuum system is used to remove the air in the launch tube, diagnostic tank, and catcher tank assembly. This removes the effect of having a layer of gas compressed in front of the projectile. Such a gas layer would cause the sample being investigated to have a small pre-compression, which is undesirable.

The launch tube, diagnostic tank and catcher tank assembly is under a vacuum of less than 100 mTorr. This could potentially cause the projectile to be sucked down the barrel towards the diagnostic tank and catcher tank assembly. This is due to a pressure difference between the diagnostic tank and catcher tank assembly and the projectile cavity. To prevent this movement, a vacuum of equal magnitude to the diagnostic tank and the catcher tank assembly is required in the projectile cavity to eliminate this pressure difference.

The current vacuum pump takes about 90 minutes to evacuate the launch tube, diagnostic tank and catcher tank assembly to less than 100 mTorr;

however, with the integration of a turbo vacuum pump, the time required could be reduced further (Refer to Figure 21. Circuit Diagram for Combined Vacuum and Pressure System).

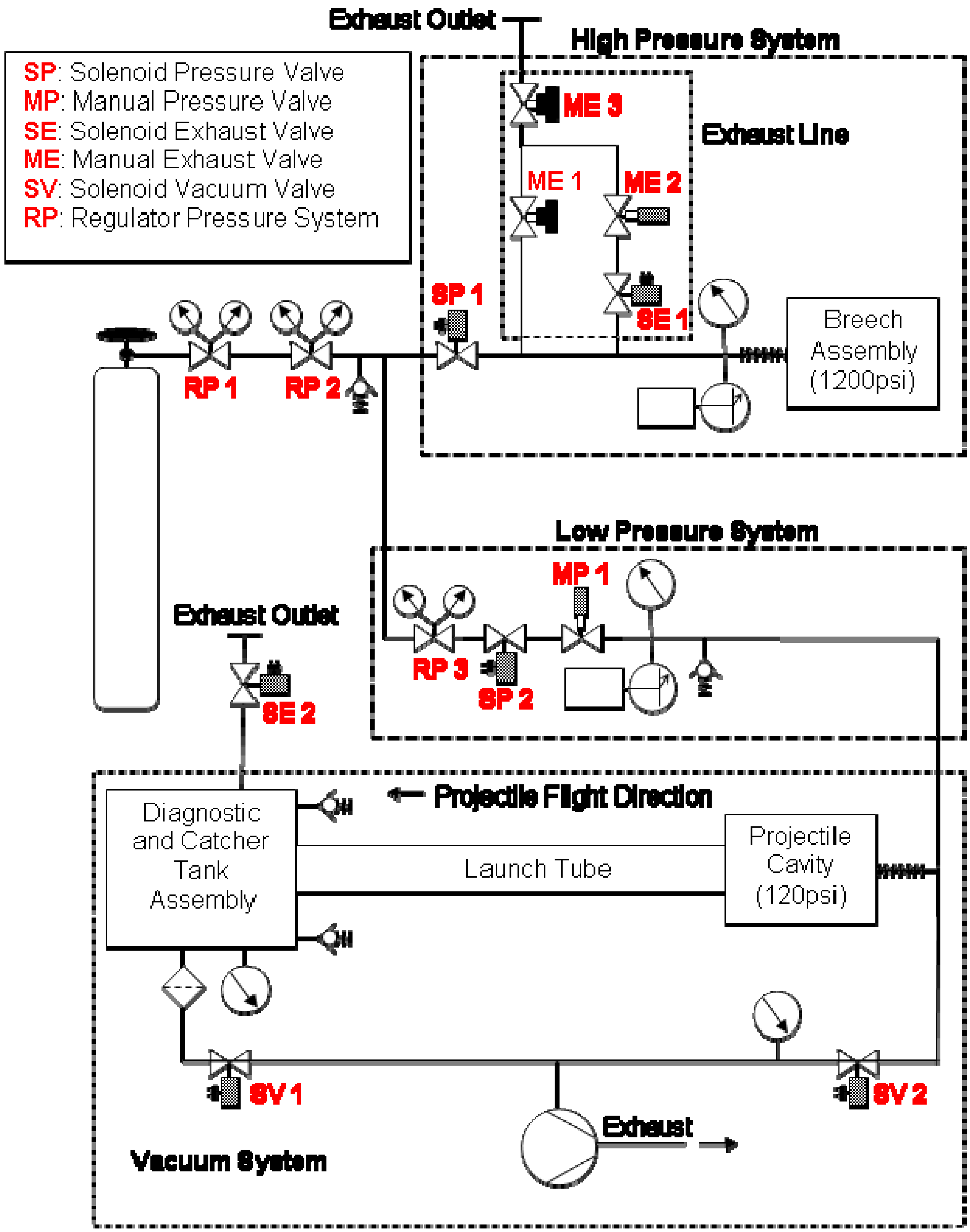

Figure 21. Circuit Diagram for Combined Vacuum and Pressure System

D. CONTROL PANEL ASSEMBLY

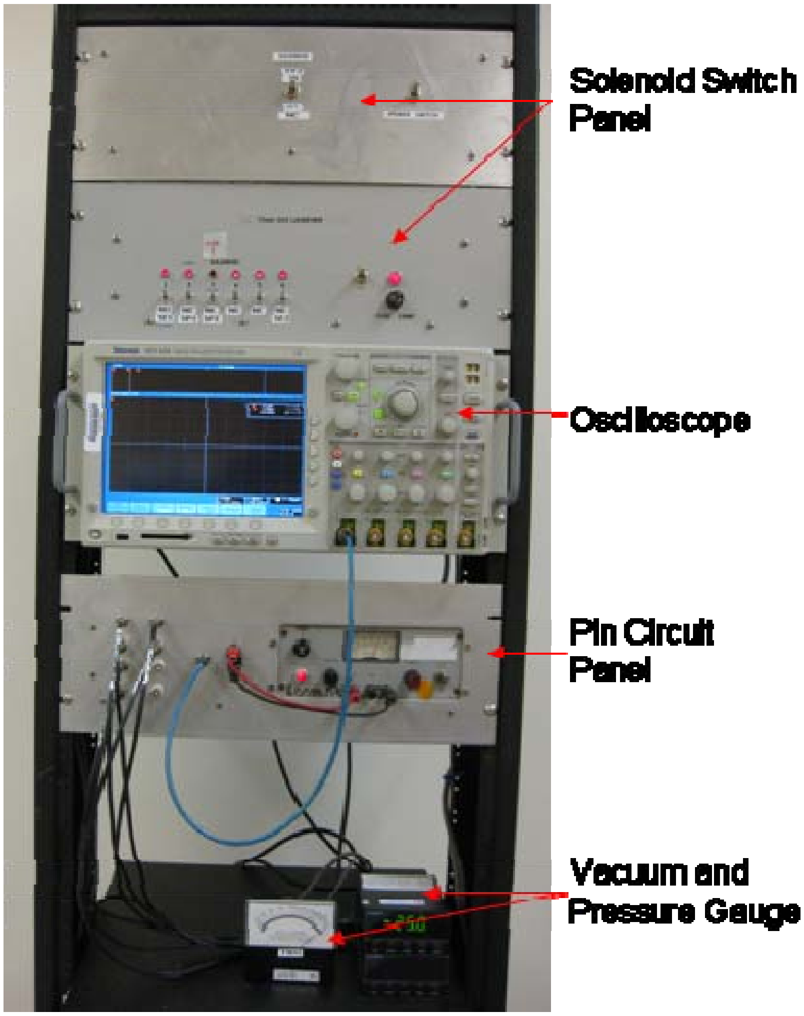

Figure 22. Control Panel Assembly

The control panel assembly provides the user of the gas gun with information on the status of the gun's systems. As a safety requirement, no one is allowed in the room where the gas gun is housed while the projectile is launched. Thus, the control panel allows the user of the gas gun to operate and monitor the gas gun from a separate room. The control panel assembly consists of the following items:

a. Switches to control the solenoid valves for the pressure system
b. Switches to control the solenoid valves for the vacuum system
c. pin circuit panel
d. Oscilloscope
e. Vacuum and pressure gauges

E. TARGET PLATE AND PROJECTILE

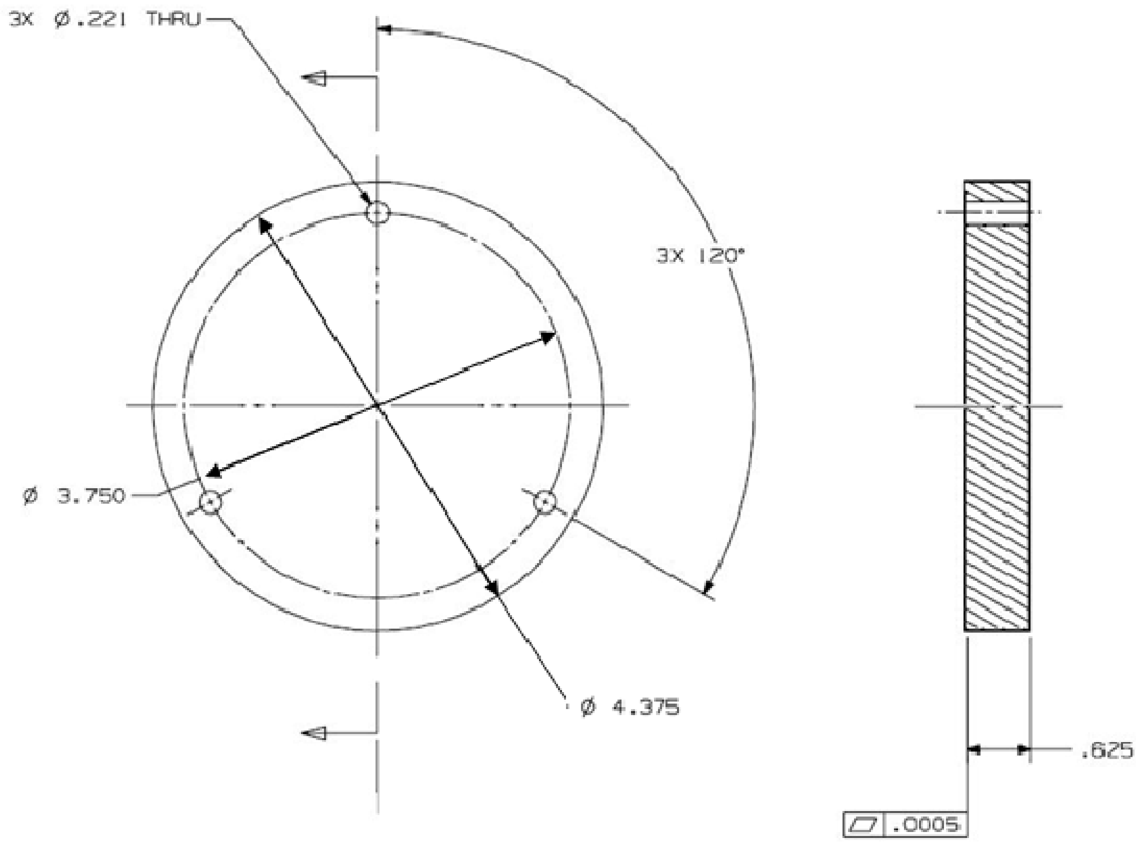

Figure 23. Manufacturing Drawing of the Target Plate [After 5]

The target plate used for planar impact testing is fabricated according to Figure 23. Manufacturing Drawing of the Target Plate [After 5].

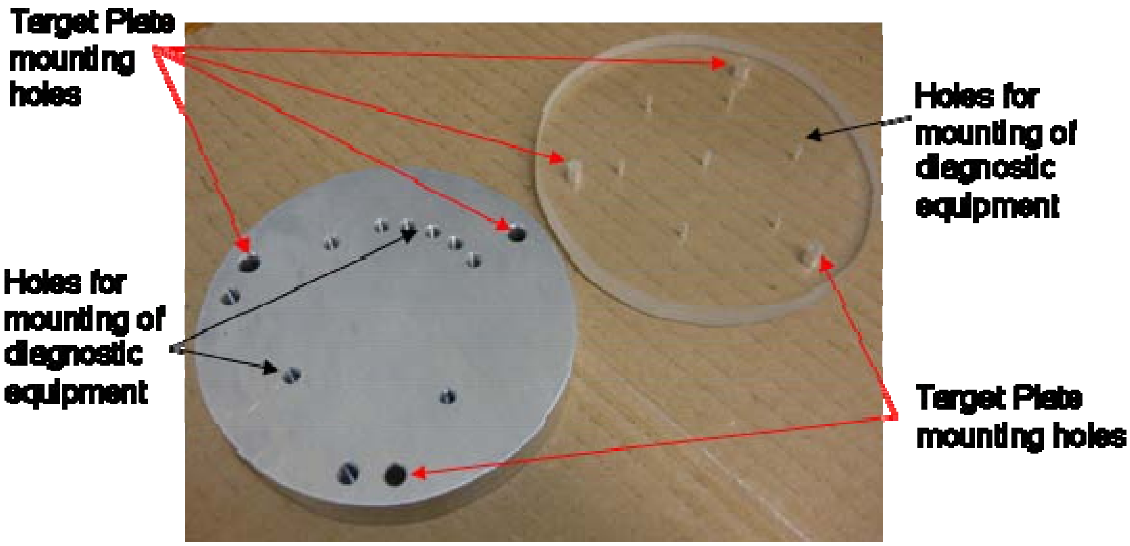

Figure 24. Examples of Target Plates

The projectile used for planar impact testing is to be made according to the dimensions shown in Figure 25. Manufacturing Drawing for Projectile [After 5]. The two rubber seals on the projectile are used to seal the ports on the launch tube, and to prevent gas from blowing around the projectile during its flight down the barrel. A photograph of the projectile is shown in Figure 26.

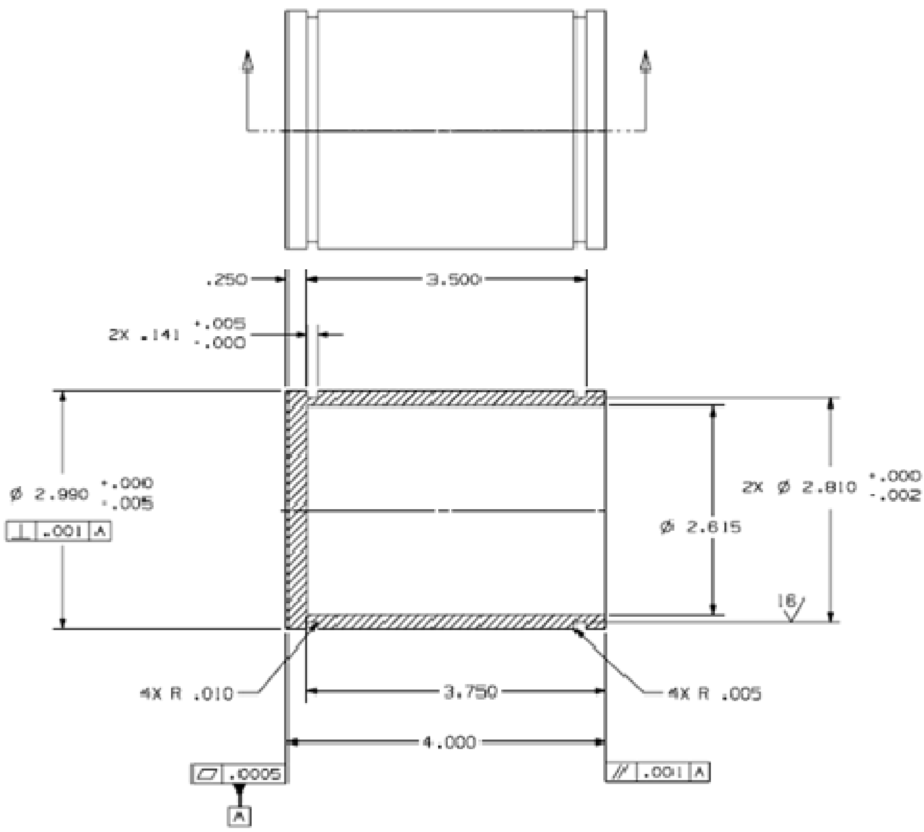

Figure 25. Manufacturing Drawing for Projectile [After 5]

Figure 26. Projectile

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III. GAS GUN ASSEMBLY

A. GAS GUN ASSEMBLY

The gas gun is assembled in four phases. In the first phase, the components of the main gun assembly are assembled. In the second phase, the vacuum system is assembled and coupled onto the main gun assembly. Then the system is tested for leaks. In the third phase, the high- and low-pressure system plumbing is routed and coupled onto the main gun assembly. Both the high- and low-pressure systems are subjected to a low-pressure leak test after the solenoid valves are connected in the final phase. For the final phase, all the wiring is routed and connected from the gas gun assembly to the control panel assembly. Then the wiring is functionally checked.

B. PHASE ONE – MAIN GUN ASSEMBLY

The main gun assembly is assembled with reference to the assembly drawings from SNL (Refer to Appendix A). The assembly process starts with leveling the horizontal datum surface (machined top of the main support beam). Then, the diagnostic tank assembly, catcher tank assembly, launch tube support assembly and launch tube were installed onto the horizontal datum surface. Next, a laser alignment tool is used to align these sub-assemblies. Once these sub-assemblies are in-line, fasteners are installed and torqued to the required specification. Careful alignment is required as the catcher tank assembly is designed to translate between two points on the system; the preparation and launch positions. The alignment of the experimental chamber also acts as a reference for the alignment of the launch tube to the target plate.

The same laser alignment tool is used for the final alignment of the launch tube to the diagnostic tank front plate. A laser is inserted in the breech end of the barrel and the beam is reflected from the target plate's mirrored surface. This results in a reflected laser beam, the offset of which, relative to the barrel axis is

then observed at the breech end of the barrel. The launch tube and target plate are required to be aligned to less than 1×10^{-3} radian, where the reflected laser beam must fall within a radius of 0.1063 inch from the center of the laser alignment tool. The alignment can only be finally verified after conducting a firing test. To adjust the tilt of the launch tube relative to the diagnostic chamber, the three support screws on each of the three launch tube supports must be adjusted in the correct sequence to move the barrel in the required direction. Once the required alignment is achieved, the support screws on the Launch Tube must be tightened to secure the launch tube in place. The final step in this process is to remove the laser alignment tool and install the breech assembly.

For detailed steps on the gas gun assembly, refer to Appendix B.

C. PHASE TWO – VACUUM SYSTEM

In the second phase of the assembly process, the vacuum system is connected and tested as per Figure 28. Circuit Diagram and Parts List of Vacuum . The vacuum system is connected using one inch ISO KF tubing and fittings.

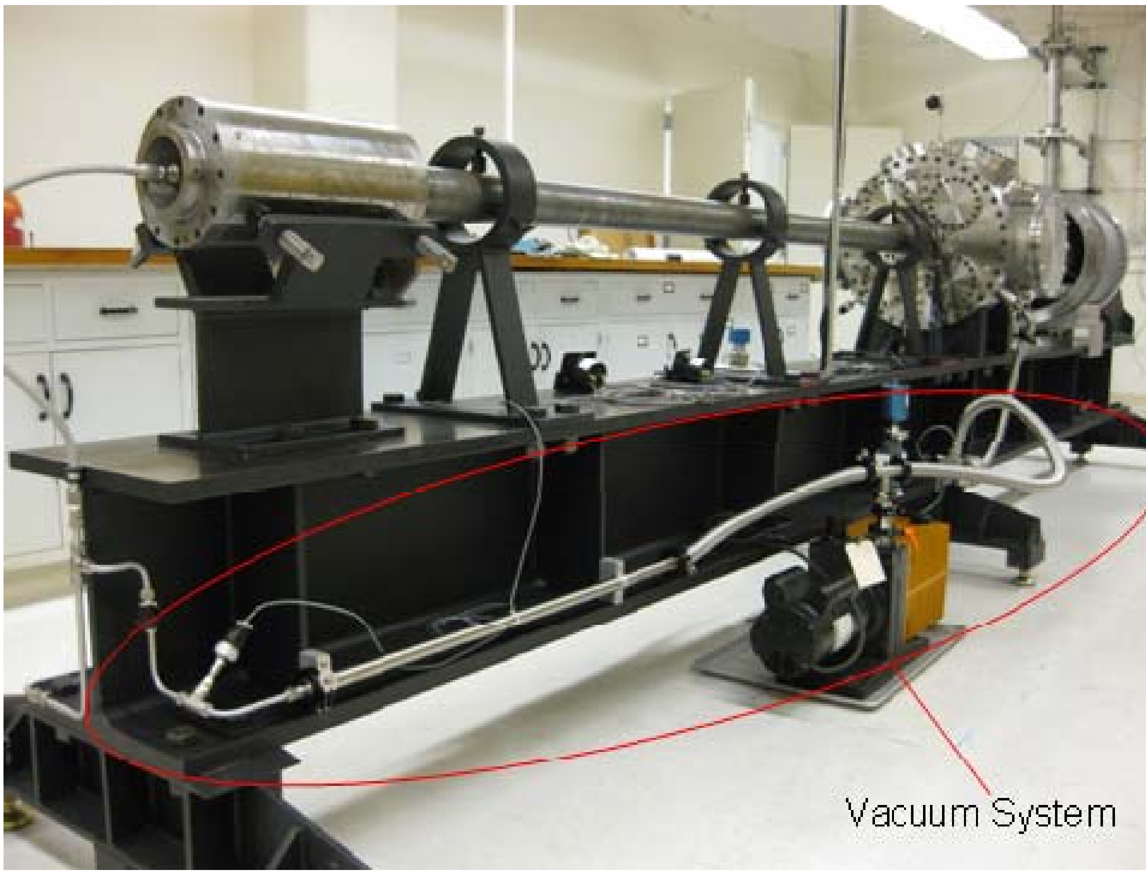
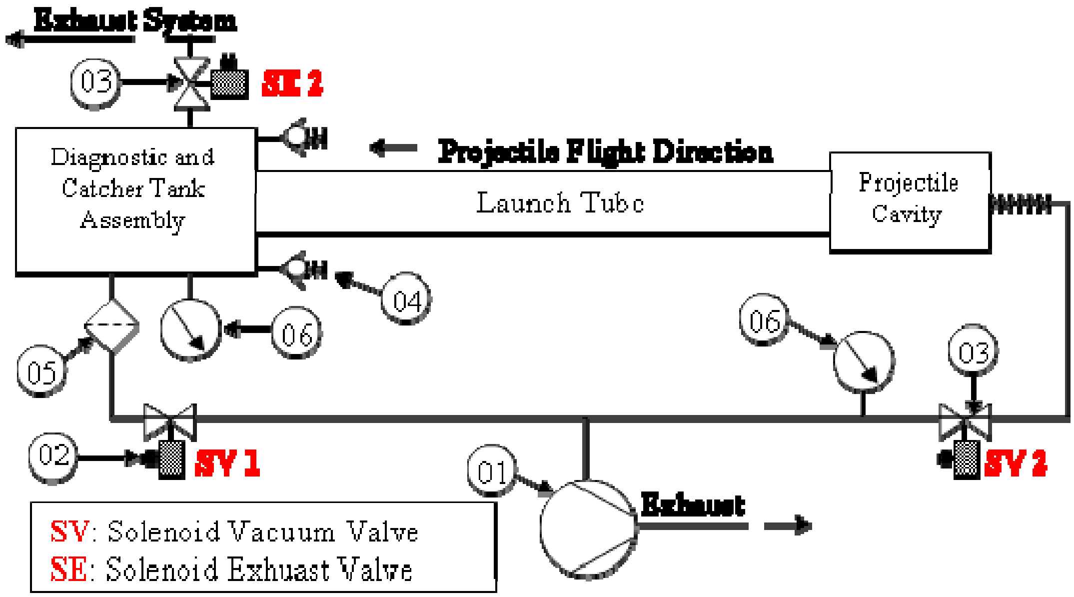


Figure 27. Main Gun Assembly Integrated with Vacuum System



Part List for Pressure System	
Item No.	Item Description
1.	Vacuum Pump
2.	BOC EDWARDS - CPV26EKA Solenoid Valve
3.	Circle Seal Valve (Solenoid) - SV10T2NC 4P3E
4.	Pressure Relief Valve
5.	Filter
6.	Varian Thermocouple Vacuum Gauge Tube Model 531 and Varian 800 Series Thermocouple Vacuum Gauge Controls

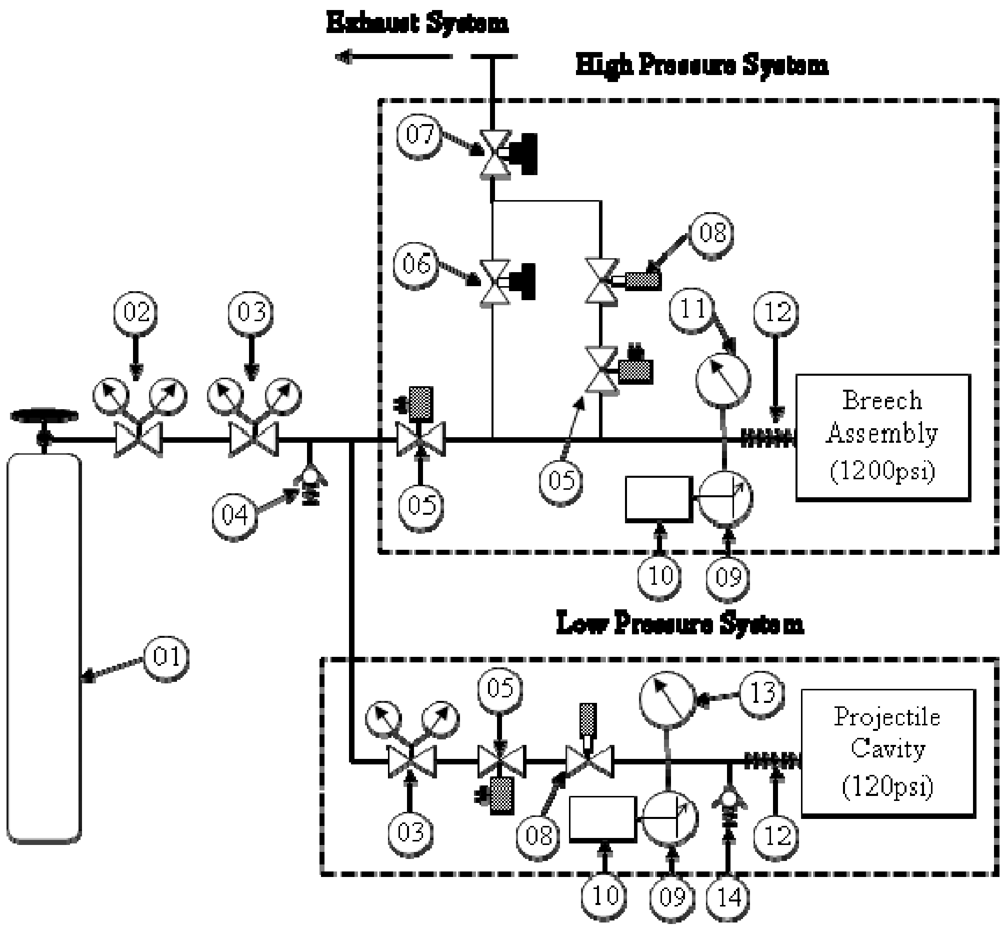
Figure 28. Circuit Diagram and Parts List of Vacuum System

Once the vacuum system is connected, a system vacuum test is conducted on the integrated system. This test confirms that the system is free of leaks. The system is required to be evacuated down to less than 100 m Torr, which is not possible if there is any significant leakage. A helium leak detector as shown in Figure 29. Helium Leak Detector is used to detect and repair the initial leaks within the system.

Figure 29. Helium Leak Detector

D. PHASE THREE – PRESSURE SYSTEM

In the third phase, the pressure system is connected in accordance with Figure 30. Pressure Circuit and Partlist for High and Low Pressure System and integrated onto the main gun assembly. The pressure system is connected using 3/8-inch stainless steel tubing and stainless steel Swagelok fittings. A functional test for the pressure system is conducted at 100 psi. During this test, any leaks detected using the helium leak detector must be repaired.



Part List for Pressure System	
Item No.	Item Description
1.	6000psi Helium Tank
2.	6000psi Pressure Regulator (ProStar – PRS 409259)
3.	4000psi Pressure Regulator (Matheson – 3040580)
4.	Pressure Relief Valve (1500 -2500 psi)
5.	Circle Seal Valve (Solenoid) - SV10T2NC 4P3E
6.	16DKS6 (Non-Rotating, Stem, Needle)
7.	SS-1RS6 (Course Flow Restrictor)
8.	SS-6L-MH (Fine Metering Valve)
9.	Omega PX4201-3KGV, (0-3000psi)
10.	Omega, DP24-E (Process Meter)
11.	Matheson, MSN 63-3143 (High Pressure Gauge)
12.	Western, PF-4SS-24 (Flex, ¼ fpt). With Swagelok SS-QC4-S4PM and SS-QC4-B-4PM
13.	Matheson, MSN 63-3143 (High Pressure Gauge)
14.	Pressure Relief Valve (150 -350psi)

Figure 30. Pressure Circuit and Partlist for High and Low Pressure System

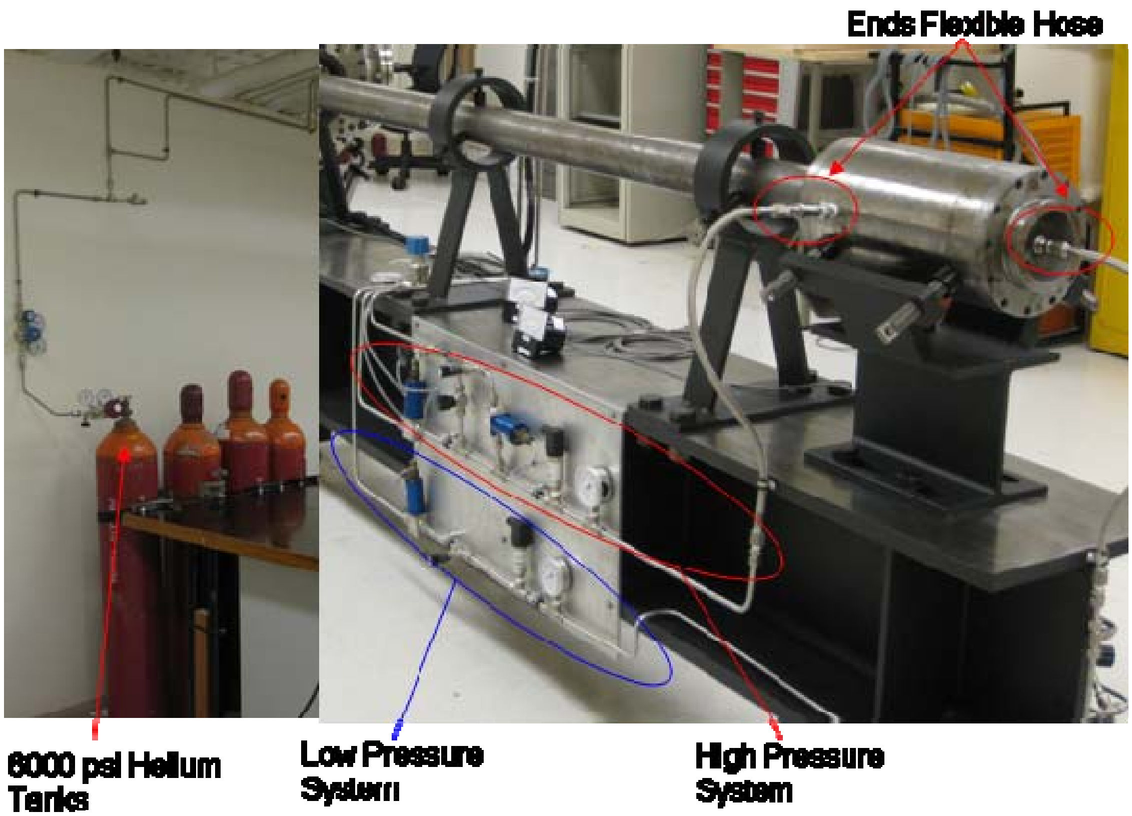


Figure 31. Picture of Pressure System

E. PHASE FOUR – CONTROL SYSTEM

In the fourth and final assembly phase, all the wires required for the connection of the solenoid valves, pressure gauges, vacuum gauges, and diagnostic terminals are routed from the main gun assembly to the control panel assembly. Next, the system components are wired together. A functional check for the control system is conducted to ensure that the connections to the respective components are completely operational.

With functional control to the solenoid valves in the pressure system established, an initial pressure test is conducted. To conduct the pressure test, the two fixable hoses are disconnected from the breech assembly (Refer to Figure 31. Picture of Pressure System). The ends of the hoses are terminated with plugs; this termination creates a closed-pressure system. This facilitates

testing of the pressure system, exclusive of the breech assembly. After the pressure test, the residual pressure within the pressure system is discharged via the exhaust system. After the pressure test, the ends of the flexible hoses are reconnected to the breech assembly.

IV. DIAGNOSTIC SYSTEM

A. PIN CIRCUIT SYSTEM

The gun gas is currently equipped with the capability to measure the velocity and tilt of the projectile at impact. This is done via a pin circuit system connected to an oscilloscope.

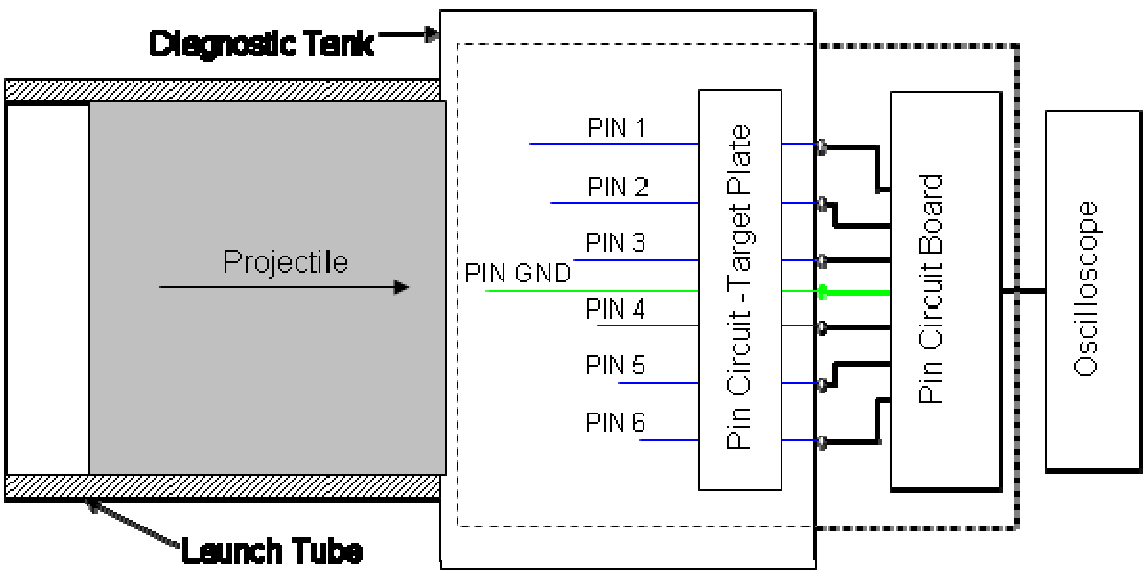


Figure 32. Pin Circuit System

The pin circuit electrical contacts are the pins on the target plate. Stainless steel sewing needles are used as contact pins. The pins are arranged in a circular stepped array with a height increment of 2 millimeters (mm) between pins. The pins are mounted on the target plate and held in place with epoxy adhesive, (Refer to Figure 34. Picture of Target Plate with Pins). The pins are equally spaced on a circle with a diameter of 2.5 inches. For the pin circuit to function, these pins must be insulated from the grounded center pin and the target plate (Refer to Figure 33. Pin With Insulation).

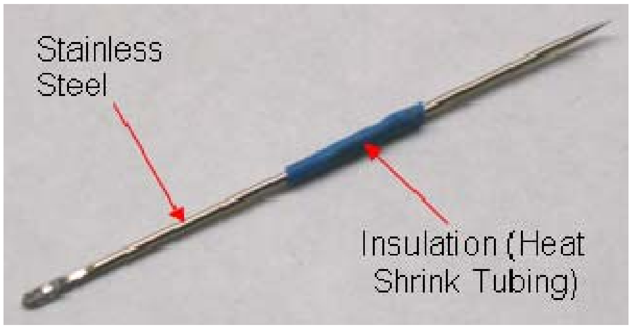


Figure 33. Pin With Insulation

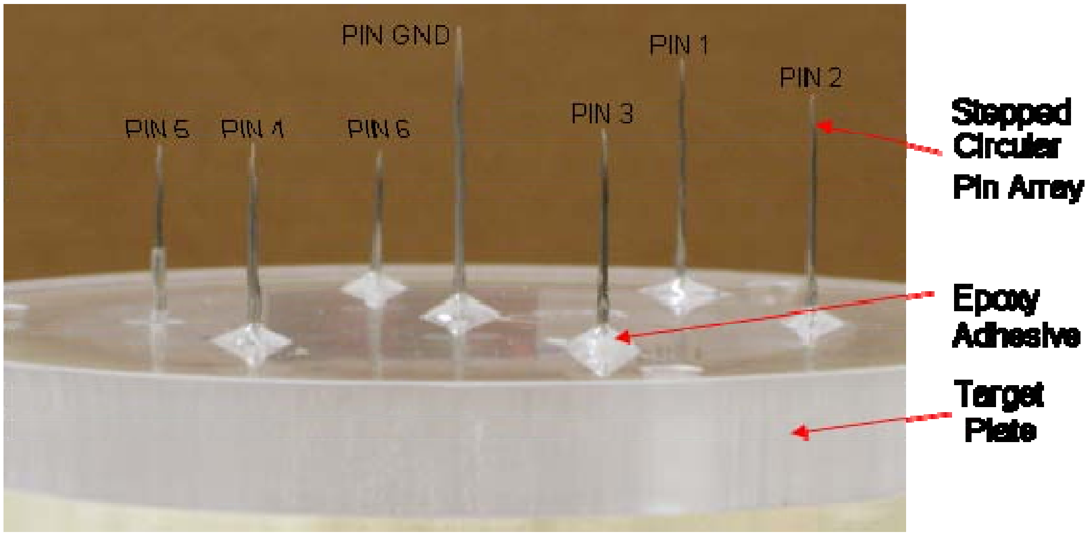


Figure 34. Picture of Target Plate with Pins

Two pin circuit boards are used in the diagnostic system. These pin circuit boards were designed and provided by SNL. Each circuit board is designed to function with four pins (Refer to Figure 35. Two Pin Circuit Boards). Each pin is connected individually to a dedicated charged capacitor on the pin circuit board. When the pin is grounded, the charged capacitor discharges the stored charge. This causes a voltage spike, which is measured with a digital oscilloscope. The pin circuit system transmits all six voltage spikes to the oscilloscope via a single BNC cable.

The projectile contacts the pins prior to impact on the target plate. The first pin to contact the projectile is the ground pin, thus grounding the projectile. Then

the projectile contacts pin 1. This causes the circuit to be closed, resulting in a voltage spike that is recorded in the oscilloscope. Next, the projectile will close the circuits to pin 2, pin 3, pin 4, pin 5, and pin 6, respectively. By using the oscilloscope to measure the times at which these impacts occur and knowing the spacing of the pins, an analysis by a computer program determines the projectile's tilt and velocity, and any uncertainties in these values.

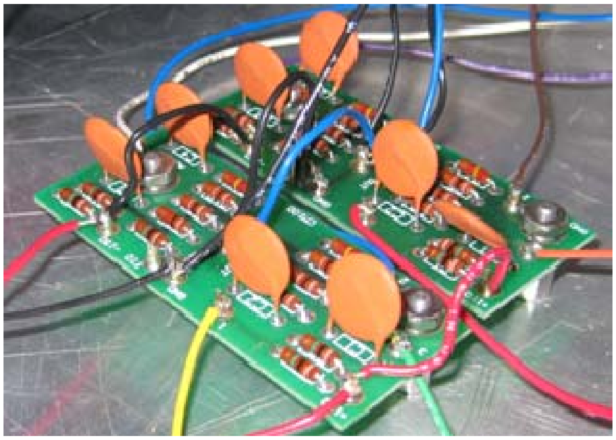


Figure 35. Two Pin Circuit Boards

B. PROJECTILE AND TARGET PLATE PREPARATION

Before the impact test, the projectile needs to be weighed. For the first test, the weight of the aluminum projectile was determined to be 0.349 kilogram (kg).

The pins mounted in the target plate are prepared according to the following list requirements:

- Six through holes of diameter 0.08 inch are required on the target plate for pins 1 to 6.
- These holes are equally spaced, with 60 degree spacing.
- The pins are arrayed in a circle with a diameter of 2.5 inch. This is well less than the 3 inch bore of the gun barrel.

- One through hole of diameter 0.08 inch is required on the target plate for the grounding pin.
- A through hole of about 0.08 inch is required for a piezoelectric pin. This pin is used to trigger the VISAR diagnostic.

For a view of the target setup, refer to Figure 36. Target Plate with Pin Configuration.

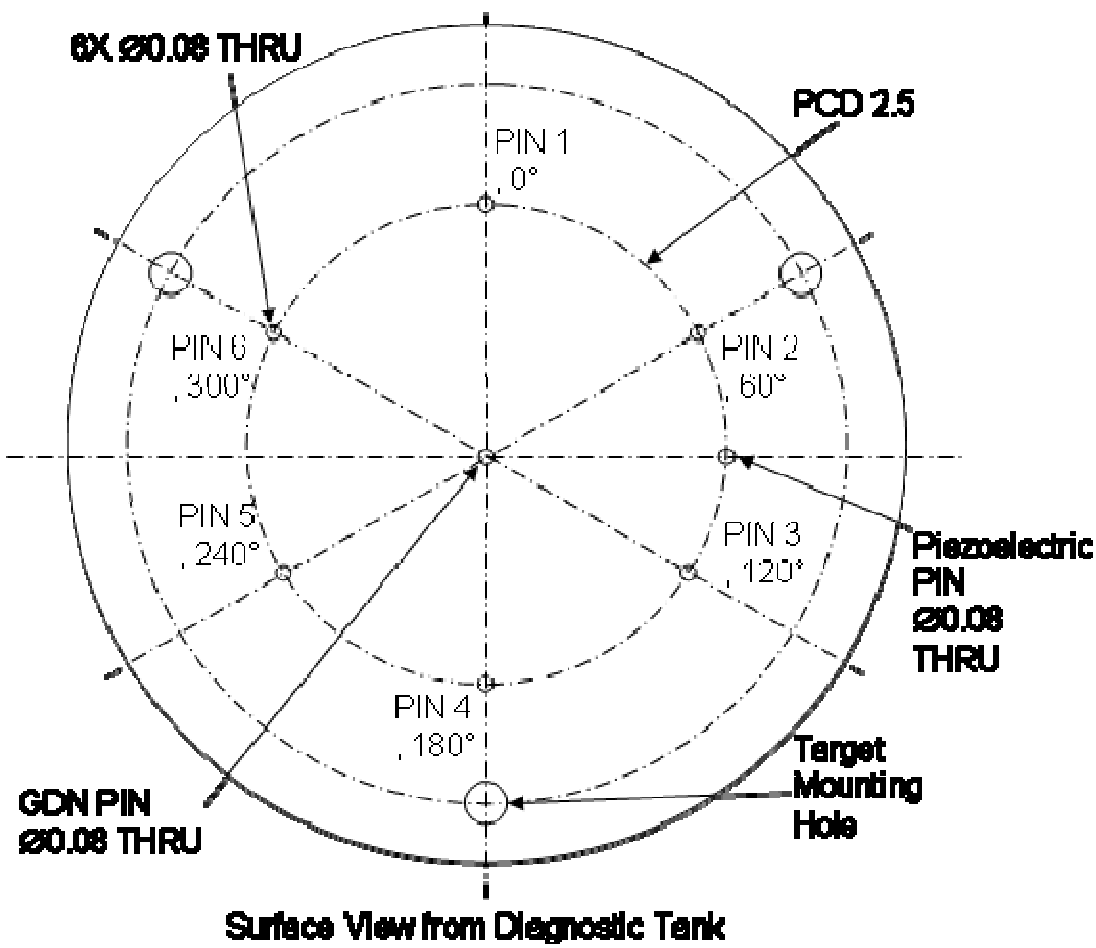


Figure 36. Target Plate with Pin Configuration

To set the pins to the required height on the target plate, a pin setup jig is used (Refer to Figure 37. Target Plate and Pin Setup Jig). Once the pins are in position, quick-dry epoxy adhesive is used to glue them into place. After the

epoxy cures and the pins are held firmly in position, the heights of the pins are measured and the ends of the pins are soldered to wires (Refer to Figure 40. Target Plate with Soldered Terminals), which connect the pins to the BNC terminals in the diagnostic tank. The grounding pin must be grounded to the diagnostic tank.

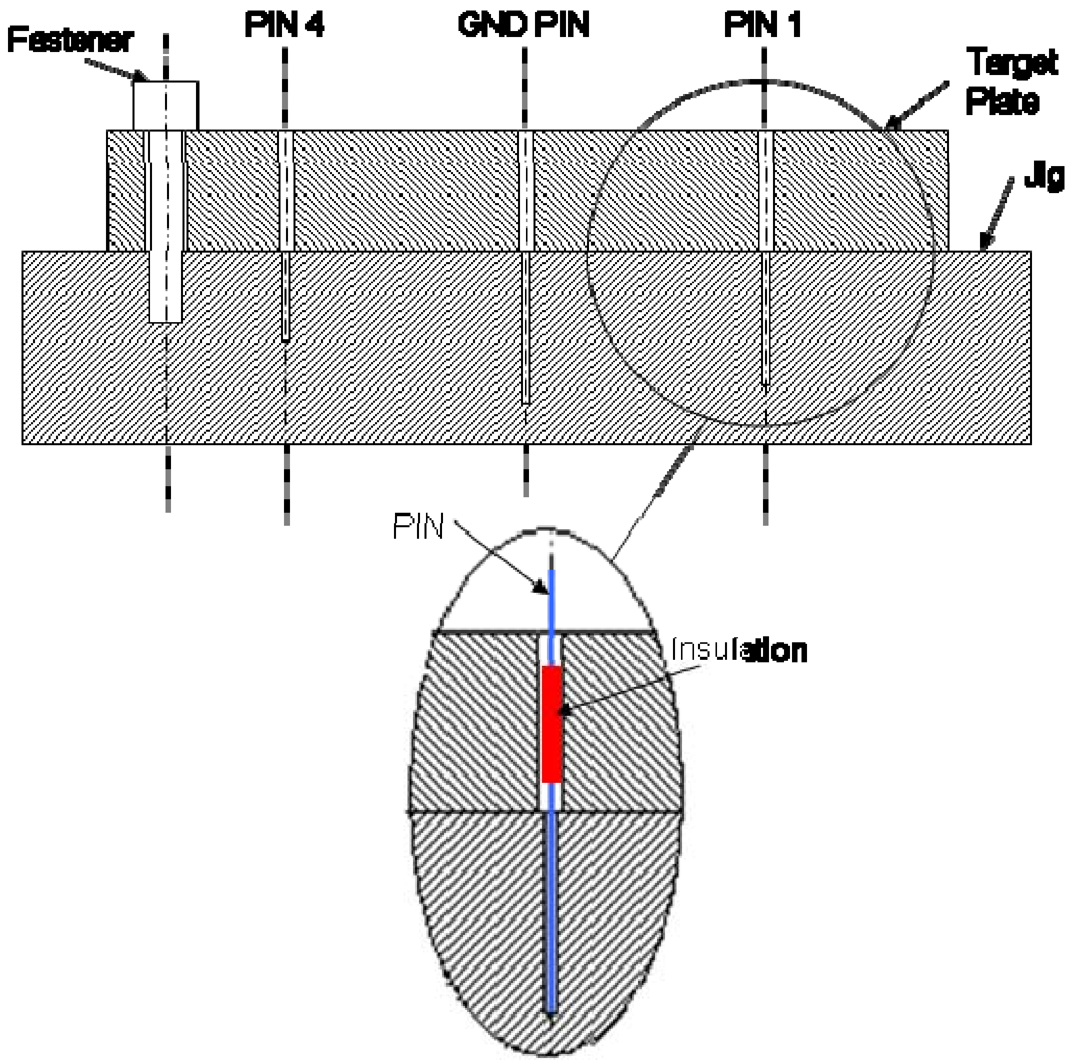


Figure 37. Target Plate and Pin Setup Jig

To determine the height of the pins, a vertical venire is used. The target plate is placed on the target holder, where a recess is catered to house the wired end of the pin. All measurements must be taken on a flat machined surface. (See Figure 38. Setup to Measure Pin Height)

The shortest pin is set as the datum, with the upper slider secured. The micro screw on the upper slider is used to move the venire to the next higher pin. The process is repeated to record the height of all six pins, which is required for data processing later.

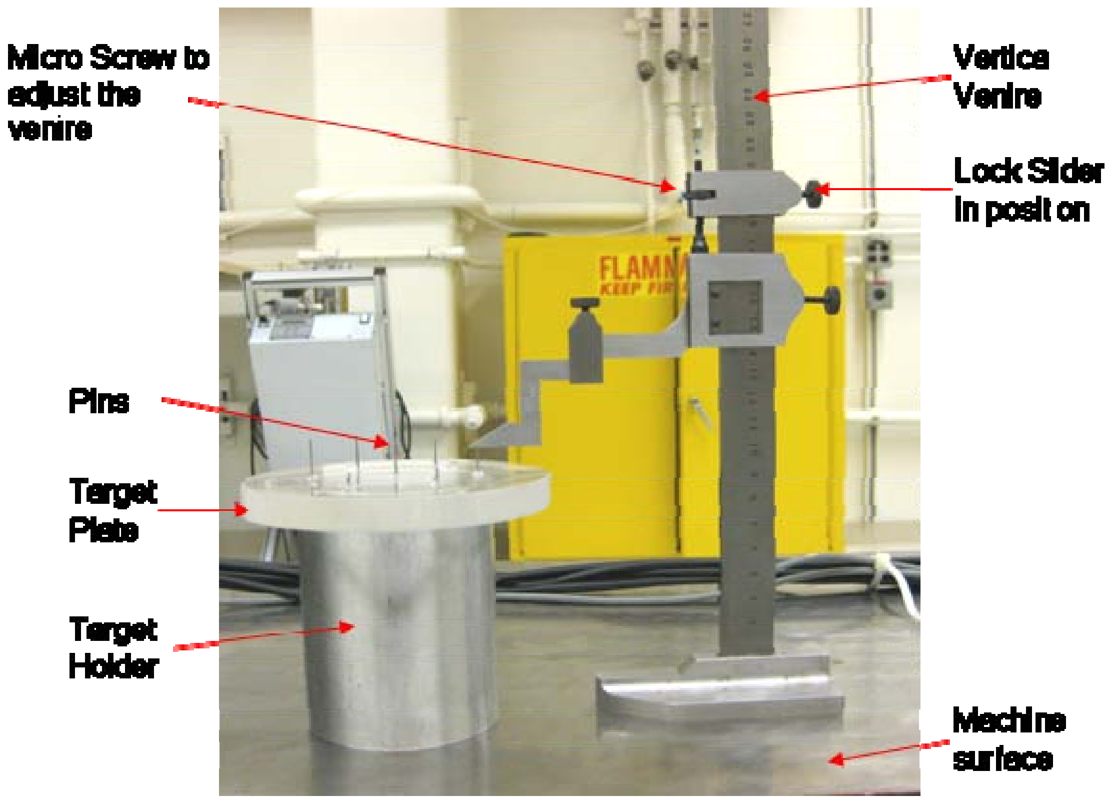


Figure 38. Setup to Measure Pin Height

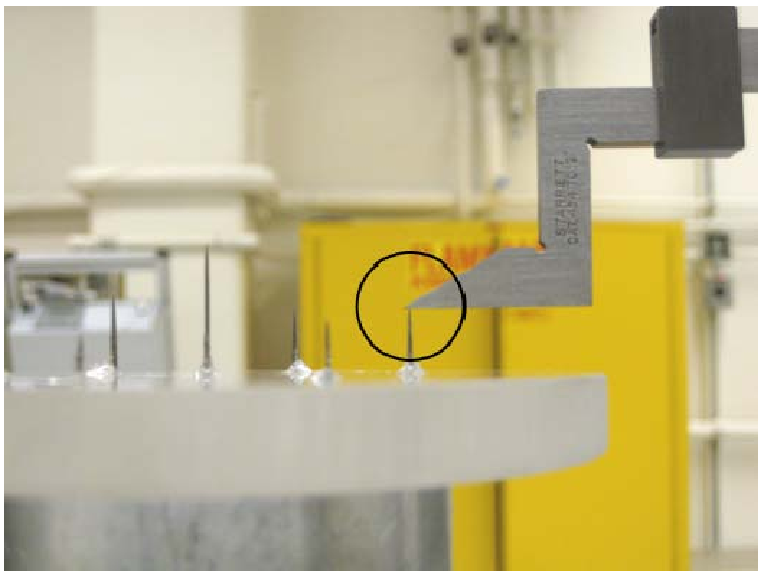


Figure 39. Venire in Contact with Pin for Measurement

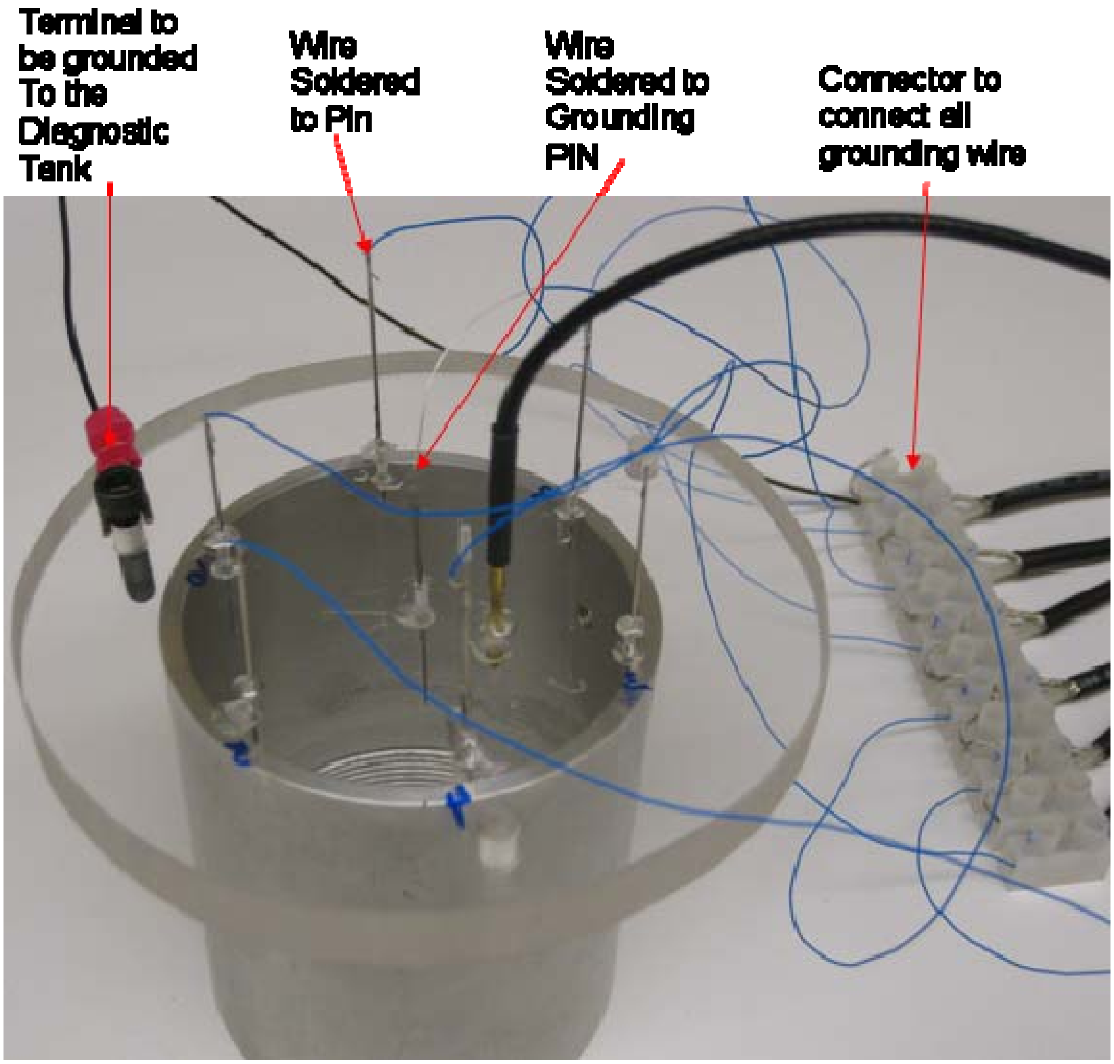


Figure 40. Target Plate with Soldered Terminals

C. DATA PROCESSING

After the impact of the projectile and the target plate, six voltage spikes should be recorded on the oscilloscope. The timing between the voltage spikes is critical for determining the projectile velocity and tilt of impact.

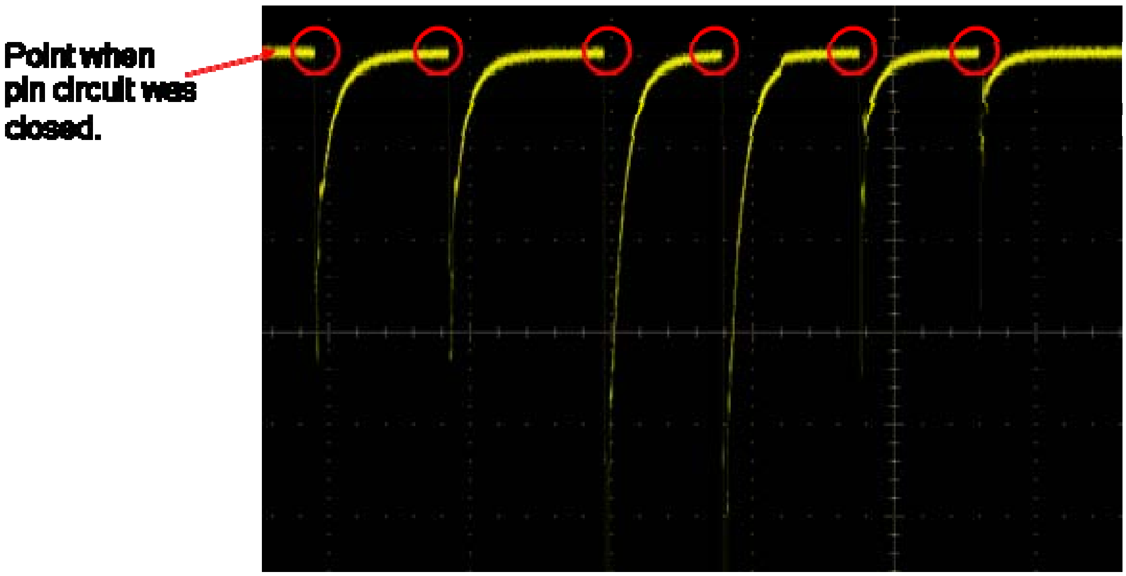


Figure 41. View of Oscilloscope with Voltage Spike

Figure 42. Time Difference Measured on Oscilloscope

1. Velocity of Projectile at Impact

To determine the velocity of the projectile at impact, a very basic equation is used:

$$V = \frac{\Delta X}{\Delta t}$$

$$\begin{aligned} where \quad \Delta X &= \text{Height difference between 2 consecutive Pins} \\ \Delta t &= \text{Time difference between 2 consecutive Voltage Spike} \end{aligned}$$

2. Tilt of Projectile at Impact

To determine the tilt at impact, the time differences between consecutive pins are assessed. As the height difference between two consecutive pin is constant, where ΔX = 2mm, for a flat impact, the time difference between all the pins must be the same.

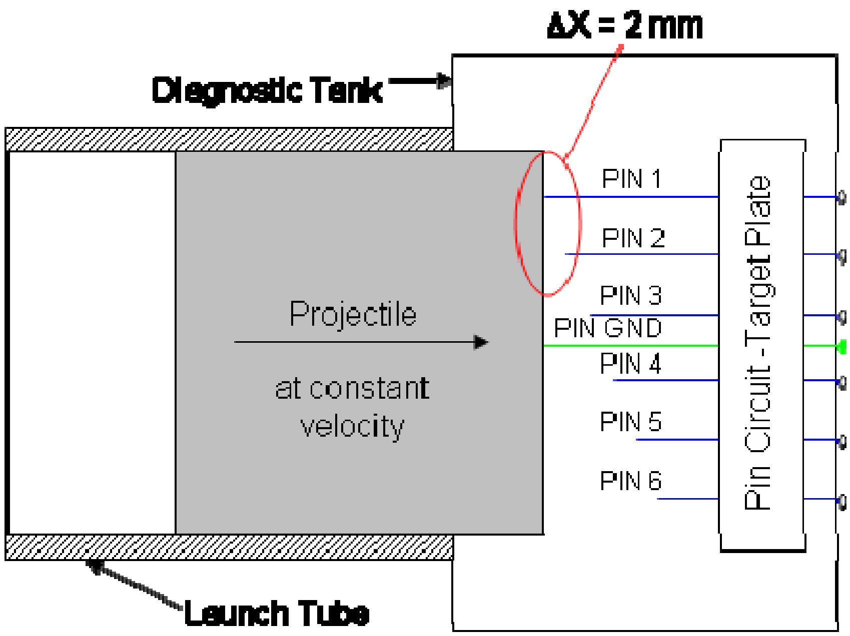


Figure 43. Projectile Contact Pin

With reference to the circular array, when the impact is not flat, the time difference (Δt) between the opposite pin is different from the nominal. For example, a tilted projectile will reduce the pin distance (ΔX-T) for Pin 4, thus reducing Δt. It will also increase the pin distance (ΔX+T) for Pin 1, and thus increase Δt, where T is the distance and Tt is the time difference from nominal Δt. Refer to Figure 44. Tilted Projectile Illustration.

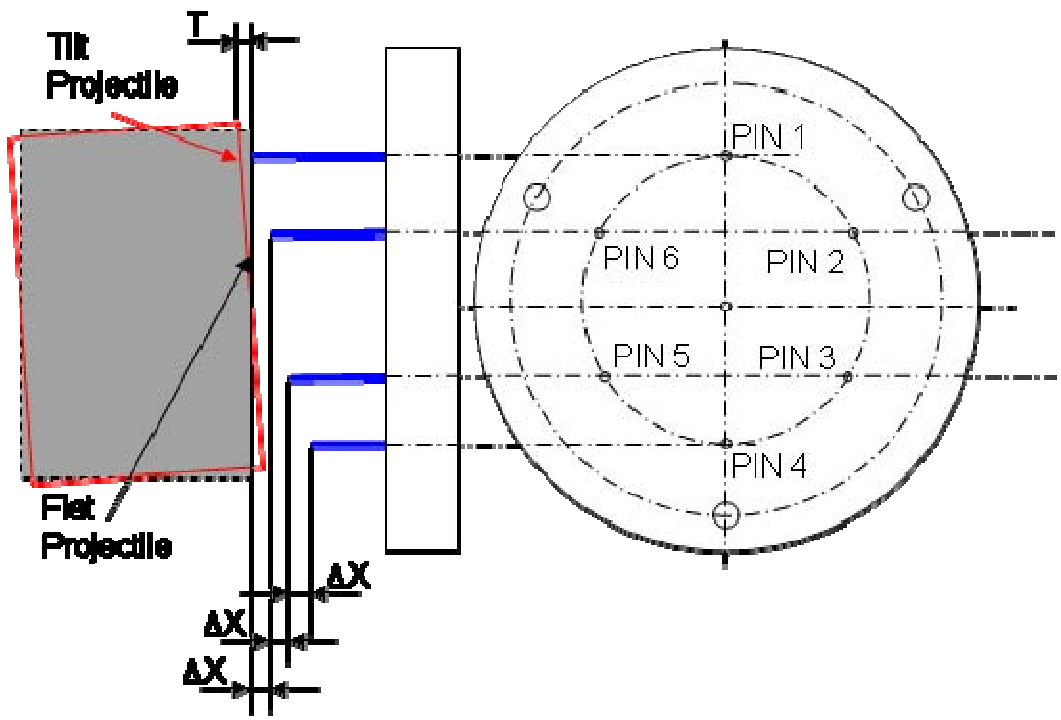


Figure 44. Tilted Projectile Illustration

3. Software for Computation of Projectile Velocity and Tilt

With the data collected, the velocity and tilt of the projectile can be computed via a program written by J. Vorthman (private communication). To compute the velocity and tilt the following input is required:

Table 1. Software Data Input

PIN	Location (Angle, Radius) (**Refer to** Target Plate with Pin Configuration)	Pin Height, X	Time of Voltage Spike
1	300°, 1.25”	10 mm	From Oscilloscope
2	240°, 1.25”	8 mm	From Oscilloscope
3	180°, 1.25”	6 mm	From Oscilloscope
4	120°, 1.25”	4 mm	From Oscilloscope
5	60°, 1.25”	2 mm	From Oscilloscope
6	0°, 1.25”	0 mm	From Oscilloscope

With this information, the program generates the velocity of the projectile, the tilt angle, and the location of the tilt.

V. GAS GUN FIRING PROCEDURE

A firing procedure is required for the firing of the gas gun as this procedure acts as a guide to safely operating the gas gun. The gas gun firing procedure was initially generated and then modified based on actual firing experiences, and it should be updated and further refined if changes are made to the gas gun. The gas gun firing procedure is divided into three stages:

a. Before Firing – In this stage, the procedure covers the preparation work required before firing.

b. During Firing – In this stage, the procedure looks at the steps required to evacuate the gun, charge the breech with helium gas, and then launch the projectile.

c. After Firing – In this stage, the procedure covers the steps required to discharge the residual pressure, before the diagnostic tank and catcher tank can be separated to retrieve the remains of the target plate and projectile.

Table 2 shows the steps required to launch the projectile. This list also acts a checklist to ensure that all necessary preparation is executed correctly to achieve a successful impact between the target plate and the projectile, thus yielding useful results.

The steps in the firing procedure are described with reference to Figure 45. Combined System for Firing Procedure, which shows the integrated pressure system and the vacuum system.

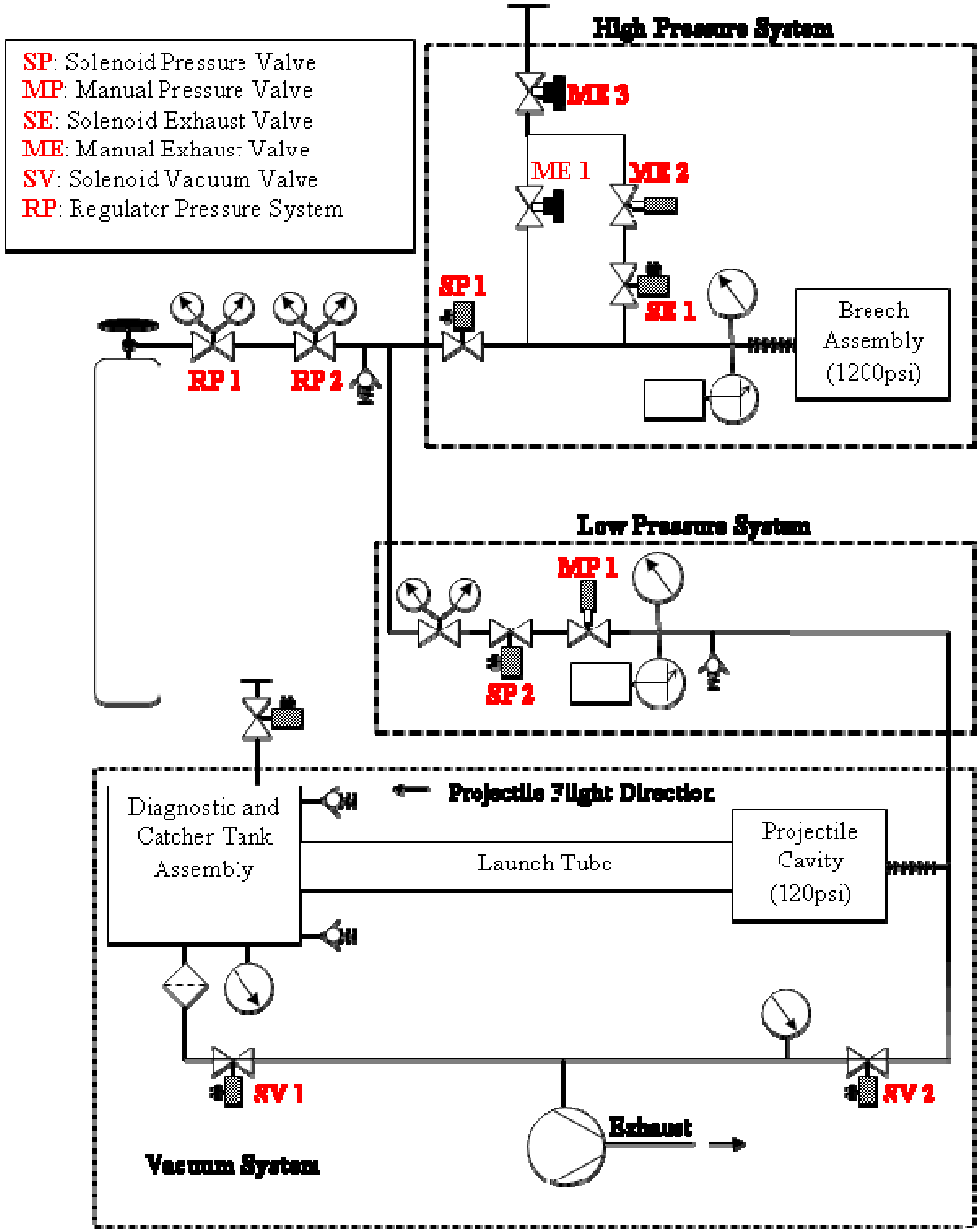
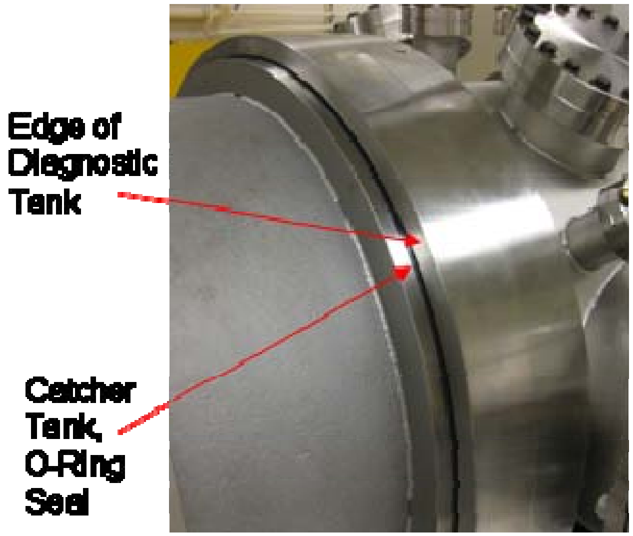


Figure 45. Combined System for Firing Procedure

Table 2. Firing Procedure

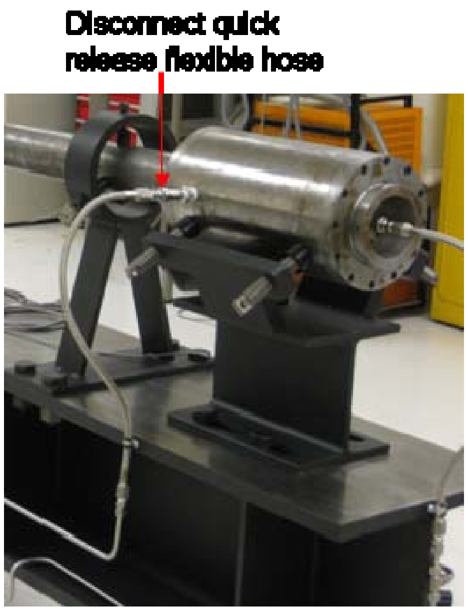
No.	Task	Action	Remarks
Please Refer to Combined System for Firing Procedure			
Before Firing			
1.	Adjust alignment of launch tube to ensure target plate is square to the face of the projectile. (Adjust only if results from previous firing is not accurate)		
2.	Diagnostic Tank preparation: a. Ensure that the launch tube is clear of foreign particles and the wipe the bore of the launch tube clean with alcohol, using an extended pole mounted with a piece of clean cloth. b. Mount the target plate. c. Connect the pins to the BNC connector, and check continuity of pin circuit and its connection to the oscilloscope. d. Clear all foreign objects. e. Ensure that the rubber O-ring seal on the diagnostic tank is coated with vacuum grease.		

No.	Task	Action	Remarks
3.	Catcher tank preparation: a. Ensure that the honeycomb energy absorber is used (4 x front and 4 x back for sliding baffler assembly) b. Clear all foreign objects from the catcher tank. c. Ensure that the rubber seal on the catcher tank is coated with vacuum grease.		
4.	Ensure that all solenoid valves are functioning.		

No.	Task	Action	Remarks
5.	Close the diagnostic tank and the catcher tank. 		

No.	Task	Action	Remarks
6.	Loading of Projectile: a. Coat vacuum grease onto the projectile's O-rings. b. Insert the projectile into the breech. Rotate the projectile within the launch tube while inserting the projectile. Ensure that the first O-ring on the projectile is inserted past the port opening off the launch tube (About 1 inch from the surface, see figure below).  c. Coat vacuum grease onto the O-ring on the launch tube plug.		

No.	Task		Action	Remarks
	d. Insert the launch tube plug into the breech. e. Secure the breech block retainer; tighten until snug. f. Attach flexible hose at the quick connect.			
During Firing				
7.	Ensure that the diagnostic system is operational and ready.			
8.	Evacuation of Gas Gun a. Ensure valves are in the following status:			
	• High-pressure exhaust solenoid valve (SE 1)	Closed		
	• Exhaust solenoid valve on diagnostic tank (SE 2)	Closed		
	• Projective vacuum solenoid valve (SV 1)	Open		
	• Diagnostic tank solenoid valve (SV 2)	Open		
	• High-pressure solenoid valve (SP 1)	Closed		
	• Low-pressure solenoid valve (SP 2)	Closed		

No.	Task	Action	Remarks
	b. Turn on the vacuum pump and monitor vacuum gauge. Once the system is at 1500 mTorr, a check on the projectile seals is required. This check is conducted by disconnecting the quick release on the flexible hose on the breech. Monitor the vacuum gauge. If the system vacuum rises, this indicates that the O-ring on the projectile is cut and must be replaced. If this test is passed, reattach the flexible hose and continue the process.  c. Vacuum to <100 mTorr.		Est. 90 mins

No.	Task		Action	Remarks
9.	Secure the catcher tank shock absorber assembly in launch position. Bolt the shock absorber assembly in position using two spring plungers and two 1.00" fasteners.			
10.	Charging of the breech a. Ensure valves are in the following status:			
	• High-pressure exhaust solenoid valve (SE 1)	Closed		
	• Exhaust solenoid valve on diagnostic tank (SE 2)	Closed		
	• Projective vacuum solenoid valve (SV 1)	Open		
	• Diagnostic tank solenoid valve (SV 2)	Open		
	• High-pressure solenoid valve (SP 1)	Closed		
	• Low-pressure solenoid valve (SP 2)	Closed		
	• Ensure that the manual valves on the pressure system are **Closed** for (ME 1), (ME 2) and **Open** for (ME 3)			
	b. Ensure that the diagnostic system is ready (triggers armed).			

<table>
<tr><th>No.</th><th colspan="2">Task</th><th>Action</th><th>Remarks</th></tr>
<tr><td></td><td colspan="2">c. Pressurize the system

• Open the helium tank cylinder valve and regulate the pressure to required launch pressure (<1200 psi), via the pressure regulator (PR 1).

• Regulate system pressure with the system pressure regulator (PR 2), to required operating pressure (< 1200 psi).

• Regulate low-pressure system with the low-pressure regulator (PR 3) to 120 psi.

Note: If system pressure exceeds required operating pressure:

• All regulators must be closed.

• Use the manual valve on the exhaust system (ME 1 and ME 3) to slowly release the pressure within the system.

• Repeat steps above to pressurize the system to correct operating pressure.</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">d. Ensure valves are in the following status:</td><td></td><td></td></tr>
<tr><td></td><td>• High-pressure exhaust solenoid valve (SE 1)</td><td>Closed</td><td></td><td></td></tr>
</table>

No.	Task		Action	Remarks
	• Exhaust solenoid valve on diagnostic tank (SE 2)	Closed		
	• Projective vacuum solenoid valve (SV 1)	Open		
	• Diagnostic tank vacuum solenoid valve (SV 2)	Open		
	• High-pressure solenoid valve (SP 1)	Closed		
	• Low-pressure solenoid valve (SP 2)	Closed		
	e. Charge the breech			
	• **Open**, high-pressure solenoid valve (SP 1) to charge the breech.			
	• Monitor the pressure gauge, **Close** high-pressure solenoid valve (SP 1) when pressure reaches the required launch pressure.			
	Note: To lower/discharge the breech pressure to the required launch pressure, the pressure in the breech can be reduced by opening the high-pressure exhaust solenoid valve (SE 1) first, then the exhaust system hand valve, and, finally releasing pressure via the metering valve.			
11.	Launch projectile a. Ensure valves are in the following status:			

No.	Task		Action	Remarks
	• High-pressure exhaust solenoid valve (SE 1)	Closed		
	• Exhaust Solenoid valve on diagnostic tank (SE 2)	Closed		
	• Projective vacuum solenoid valve (SV 1)	Closed		
	• Diagnostic tank vacuum solenoid valve (SV 2)	Closed		
	• High-pressure solenoid valve (SP 1)	Closed		
	• Low-pressure solenoid valve (SP 2)	Closed		
12.	To launch Projectile			
	• **Ensure that no personnel are in the gun room.**			
	• Ensure that the diagnostic system is ready (triggers armed).			
	• To launch the projectile, **Open** the low-pressure solenoid valve (SP 2).			
	• Close the low-pressure solenoid valve (SP 2) immediately after the projectile impacts the target plate.			
After Firing				
13.	Discharge residual pressure within the pressure system.			
	• Close the pressure supply from the helium tank.			

No.	Task	Action	Remarks
	• Close all the regulators.		
	• Open the manual exhaust valve on the pressure system.		
	• Open the manual exhaust valve on the diagnostic tank.		
	• Open the high-pressure solenoid valve (SP 1) to discharge residual pressure.		
14.	Position the shock absorber assembly back to the preparation position.		
15.	Separate the diagnostic tank and the catcher tank.		

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VI. FIRING RESULTS

A. FIRST FIRING OF GAS GUN

The first firing of the gas gun was conducted on 8 October 2009. The projectile was launched at a breech pressure of 350 psi, and the diagnostic tank and catcher tank assembly held a negative pressure of 35 mTorr. Upon impact, the oscilloscope recorded six voltage spikes from the electrical shorting pins. The following table shows the data recorded from the first firing:

Table 3. Results for First Firing

PIN	Time of Spike	Pin Height	Location	
	μ sec	(mm)	Angle (°)	Radius(mm)
1	0	10mm	300	31.75
2	6.32	8 mm	240	31.75
3	15.7	6 mm	180	31.75
4	23.6	4 mm	120	31.75
5	30.9	2 mm	60	31.75
6	38.9	0 mm	0	31.75

With the data collected, the velocity and tilt of the projectile can be computed via a program written by J. Vorthman (private communication). The computed results are shown in Figure 46. Computed Results for First Shot.

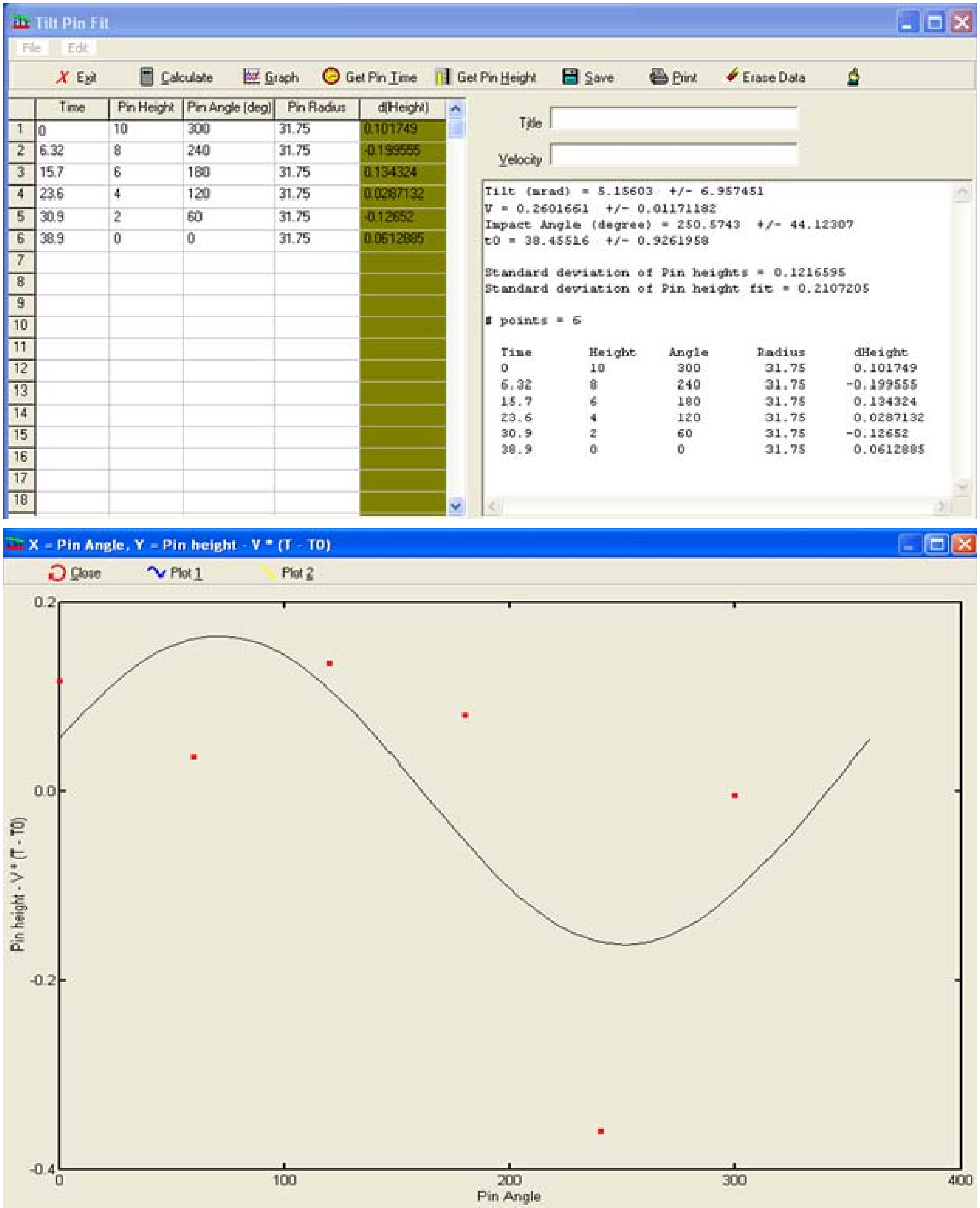

Figure 46. Computed Results for First Shot

These results show that the velocity of the projectile was 0.260km/s and the tilt of the impact was 5.16 mrad, but with greater than desired uncertainties in tilt.

From the plot generated, it was observed that the deviation of the six points generated do not lie near the curve. This is due to the inaccuracy in the height measurements of the pins on the target plate.

The tilt of the impact for the first firing was approximately 5.16 mrad, indicating that adjustment to the launch tube was required to refine the tilt of the impact.

B. SECOND FIRING OF GAS GUN

In the second firing, the projectile was launched at a breech pressure of 220 psi, The diagnostic tank and catcher tank assembly was held a negative pressure of 60 mTorr and the projectile weighed 349 grams. An additional piezoelectric pin was integrated on to the target plate. This piezoelectric pin was added to test whether if it could be used for the triggering the VISAR system for future experiments. The target plate of the second firing was prepared in accordance with Figure 40. Target Plate with Soldered Terminals

Table 4. Results from Second Firing, shows the results that were recorded from the second firing.

Table 4. Results for Second Firing

PIN	Time of Spike	Pin Height,	Location	
	μ sec	(mm)	Angle (°)	Radius (mm)
1	0.918	10.10mm	0	31.75
2	8.54	8.40 mm	60	31.75
3	19.56	6.12 mm	120	31.75
4	27.91	4.16 mm	180	31.75
5	37.68	1.82 mm	240	31.75
6	46.13	0 mm	300	31.75

With the data collected, the velocity and tilt of the projectile can be computed via a computer program. The computed results are shown in Figure 47. Computed Results for Second Firing.

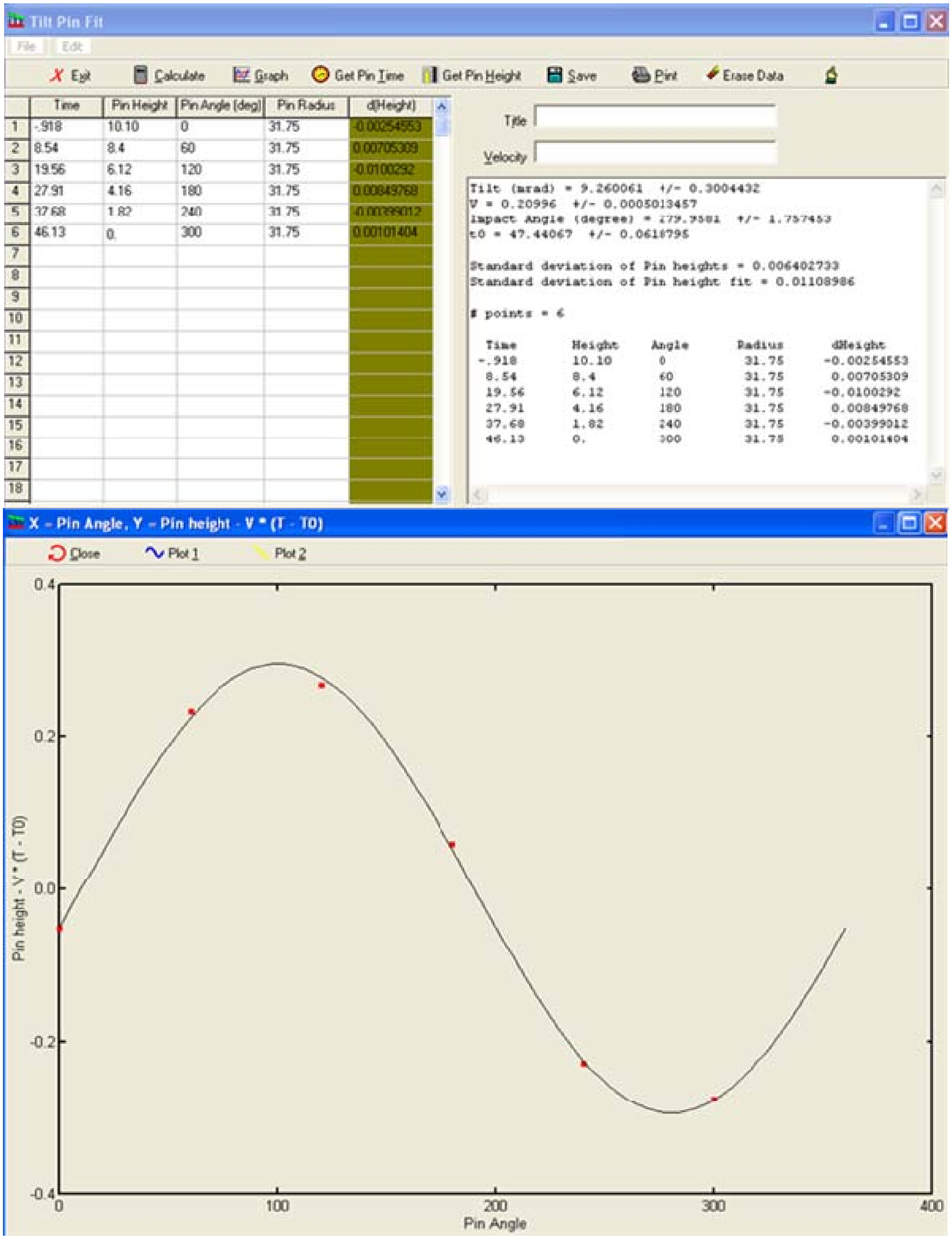

Figure 47. Computed Results for Second Firing

These results indicate that the velocity of the projectile was 0.210km/s and the tilt of the impact was 9.27 mrad.

With more accurate pin height measurements, the computed points on the plot lie on the curve with very small deviations. The tilt of the impact for the second shot, was observed to be even more than the first shot. This degradation of the impact tilt is probably due to some troubleshooting work performed just before the firing, where the breech was removed from the barrel, perhaps shifting the alignment of the launch tube.

C. SUMMARY OF RESULTS FOR NPS GAS GUN

The data collected from the NPS gas gun for the two firings were compared against the data provided by SNL using the SNL gas gun, as both the guns are of the same design.

With the available data, a plot of projectile velocity versus $\sqrt{\frac{\text{Launch Pressure}}{\text{Mass of Projectile}}}$ was generated. Refer to Figure 48. Gas Gun Performance Plot

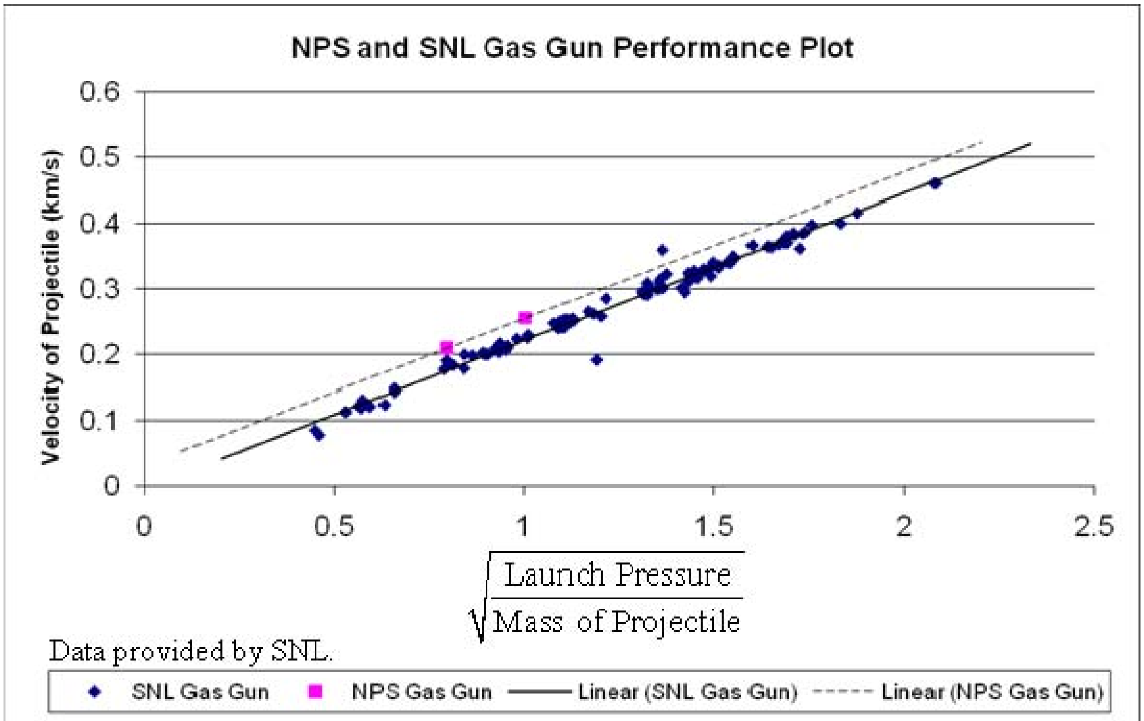

Figure 48. Gas Gun Performance Plot

From the plot, it is noted that the performance of the NPS gas gun is comparable to that of SNL gas gun.

As for the tilt of the impact, further refinement would be needed to achieve the ideal condition of less than 1 mrad, and that could only be achieved by adjusting the tilt of the launch tube and firing more shots to verify the impact tilt.

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VII. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

The main objective of the thesis is to determine if the gas gun is capable of firing a projectile onto a test material under a controlled environment for planar impact studies. To achieve this objective the gas gun was fabricated, assembled and commissioned via the firing of the first two shots.

From the results of the two firings that were conducted under a controlled environment, the initial performance curve for the gas gun was generated. The performance of NPS gas gun was compared against the performance of the SNL gas gun as both guns are of similar design. From the comparison, it is noted that the NPS gas gun performs as per designed.

We believe that the NPS gas gun is capable of firing a projectile onto the test material under controlled environment for planar impact studies. The NPS gas gun is now ready for the next phase of development, wherein the VISAR is integrated on to the diagnostic tank assembly and impact tilts are systematically improved.

The NPS gas gun is ready for the next phase of development, where the VISAR is integrated on to the diagnostic tank assembly.

B. RECOMMENDATIONS

1. Laser Alignment Adaptor

The tilt of the impact between the projectile and the target plate is one of the key parameters that must be controlled to conduct planar shock compression testing with very high accuracy. Thus, the tilt at impact performance needs to be improved until the tilt is less than $1\text{x}10^{-3}$ radian. This improvement can only be

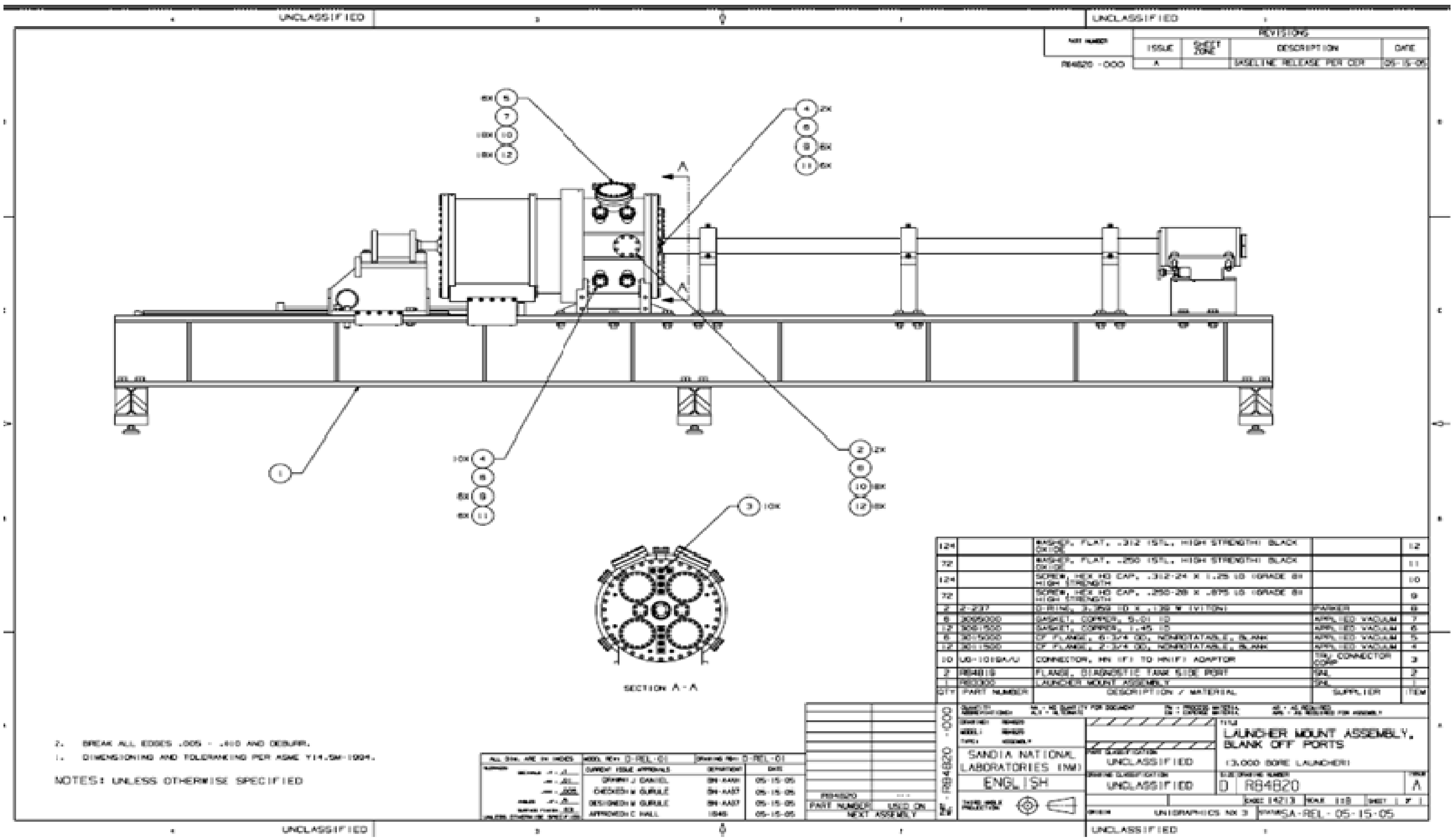
made progressively after several shots. To refine the tilt at impact, the design of the alignment adaptor needs to be improved.

The design of the current adaptor requires the breech assembly to be removed before the tilt of the launch tube can be adjusted. Thus, reassembling the breech assembly will almost certainly affect the tilt of the launch tube. An improved design for the adaptor should eliminate the need for the removal of the breech assembly. This will eliminate the effects of additional loading on the barrel (caused by the breech) after the alignment.

2. Integrated Control System

Currently, all the gas gun system controls are manually operated or monitored, where manual toggle switches are used to energize the solenoid valves and analog gauges are used to monitor the pressure and vacuum. In order for the operator to know the status of the gas gun, it is necessary to monitor various panels on the control rack. In order for the operator to have a consolidated view of the status of the gas gun, software can be used to integrate all the control systems into one panel; this is suggested as a future improvement to the control system. Software can also be used to control the solenoid valves. Finally, analog gauges should be replaced with digital gauges, thus allowing software to control the system completely.

APPENDIX A. ASSEMBLY DRAWINGS OF GAS GUN FROM SANDIA NATIONAL LABORATORIES



UNCLASSIFIED

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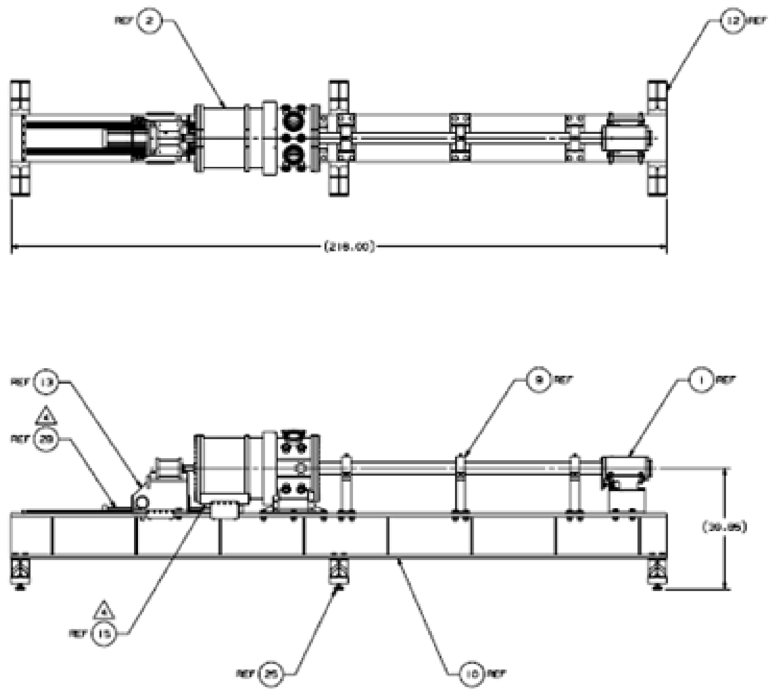
REVISIONS



QTY	PART NUMBER	DESCRIPTION / MATERIAL	SUPPLIER	ITEM
4		WASHER, FLAT, 1.00 (STL, HIGH STRENGTH) BLACK OXIDE		54
72		WASHER, FLAT, .375 (STL, HIGH STRENGTH) BLACK OXIDE		53
34		WASHER, SPLIT LOCK, 1.00 (STL, HIGH STRENGTH) BLACK OXIDE		52
30		NUT, HEX 1.00-8 (GRADE 8) HIGH STRENGTH		51
30		BOLT, HEX HD 1.00-8 X 3.00 LG (GRADE 8) HIGH STRENGTH		50
4		BOLT, HEX HD .750-16 X 3.00 LG (GRADE 8) HIGH STRENGTH		49
72		SCREW, HEX HD CAP, .375-24 X 2.25 LG (GRADE 8) HIGH STRENGTH		48
16		SCREW, HEX HD CAP, .375-24 X 1.75 LG (GRADE 8) HIGH STRENGTH		47
10		SCREW, HEX HD CAP, .375-24 X 1.25 LG (GRADE 8) HIGH STRENGTH		46
8		SCREW, HEX HD CAP, .375-16 X 1.50 LG (GRADE 8) HIGH STRENGTH		45
8		SCREW, HEX HD CAP, .250-20 X 1.00 LG (GRADE 8) HIGH STRENGTH		44
8		SCREW, HEX HD CAP, 10-32 X .50 LG (GRADE 8) HIGH STRENGTH		43
3		SCREW, SOCKET HD CAP, 10-32 X 1.00 LG (BRASS)		42
2		SCREW, SOCKET HD CAP, .750-10 X 1.50 LG (A574 STL) BLACK OXIDE		41
8		SCREW, SOCKET HD CAP, .375-24 X 1.25 LG (A574 STL) BLACK OXIDE		40
10		SCREW, SOCKET HD CAP, .375-16 X 1.50 LG (A574 STL) BLACK OXIDE		39
6		SCREW, SOCKET HD CAP, .375-16 X 1.25 LG (A574 STL) BLACK OXIDE		38
10		SCREW, SOCKET HD CAP, .375-16 X 1.00 LG (A574 STL) BLACK OXIDE		37
4		SCREW, SOCKET HD CAP, .312-18 X 2.00 LG (A574 STL) BLACK OXIDE		36
8		SCREW, SOCKET HD CAP, .250-20 X 1.00 LG (A574 STL) BLACK OXIDE		35
32		SCREW, SOCKET HD CAP, 10-32 X .875 LG (A574 STL) BLACK OXIDE		34
40		SCREW, SOCKET HD CAP, 8-32 X .750 LG (A574 STL) BLACK OXIDE		33
3	2-460	O-RING, 19.455 ID X .275 W (VITON)	PARKER	32
1	2-433	O-RING, 5.475 ID X .275 W (VITON)	PARKER	31
1	2-341	O-RING, 3.475 ID X .210 W (VITON)	PARKER	30
1	2-391	O-RING, 21.955 ID X .210 W (VITON)	PARKER	29
1	4A-12-T-SS-T36	LINEAR MOTION STAGE	SMI	28
1	HD(A) 3.0 X 2	SHOCK ABSORBER, HD(A) SERIES 3.0 X 2	ENIDINE	27
2	95165A510	QUICK RELEASE PIN, RING GRIP, 1.00 DIA	McMASTER CARR	26
9	6111K86	LEVELING FOOT	McMASTER CARR	25
8	3408A84	SPRING PLUNGER	McMASTER CARR	24
2	R83377	SHOCK ABSORBER MOUNT RAIL	SNL	23
2	R83376	DIAGNOSTIC TANK SIDE BLAST SHIELD	SNL	22
1	R83370	TARGET PLATE MOUNT EXTENSION	SNL	21
1	R83367	TARGET PLATE	SNL	20
1	R83368	TARGET PLATE MOUNT	SNL	19
2	R83365	SHOCK ABSORBER MOUNT SIDE SUPPORT	SNL	18
1	R83358	DIAGNOSTIC TANK ASSEMBLY	SNL	17
2	R83355	CATCHER TANK CRADLE SIDE SUPPORT	SNL	16
1	R83354	CATCHER TANK CRADLE	SNL	15
1	R83353	SHOCK ABSORBER MOUNT STOP BAR	SNL	14
1	R83347	SHOCK ABSORBER MOUNT ASSEMBLY	SNL	13
3	R83344	MAIN RAIL MOUNT SUPPORT FOOT	SNL	12
1	R83338	DIAGNOSTIC TANK MOUNT ASSEMBLY	SNL	11
1	R83336	MAIN RAIL MOUNT	SNL	10
3	R83331	LAUNCH TUBE SUPPORT ASSEMBLY	SNL	9
1	R83328	BREECH SUPPORT ASSEMBLY	SNL	8
1	R83318	HONEYCOMB ENERGY ABSORBER	SNL	7
1	R83317	CATCHER TANK BLAST SHIELD	SNL	6
1	R83316	CATCHER TANK END PLATE	SNL	5
1	R83315	DIAGNOSTIC TANK FRONT PLATE	SNL	4
1	R83314	SLIDING BAFFLE ASSEMBLY	SNL	3
1	R83313	CATCHER TANK ASSEMBLY	SNL	2
1	R83305	WRAP AROUND BREECH ASSEMBLY	SNL	1

4. USE SHIM MATERIAL AS NEED BETWEEN ITEMS 15 (CATCHER TANK CRADLE) AND 28 (LINEAR MOTION STAGE) TO ADJUST HEIGHT.
3. USE LIFTING EYEBOLT - PART No. 3029T14, McMASTER CARR WHERE THREADED HOLES ARE SUPPLIED IN PARTS.
2. BREAK ALL EDGES .005 - .010 AND DEBURR.
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994.

NOTES: UNLESS OTHERWISE SPECIFIED

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.XX = .01	CHECKED: W GURULE	BN-A437	05-15-05
.XXX = .005	DESIGNED: W GURULE	BN-A437	05-15-05
ANGLES .X = .5	APPROVED: C HALL	1646	05-15-05
SURFACE FINISH: 63 UNLESS OTHERWISE SPECIFIED			

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R82300	R84820

NEXT ASSEMBLY

R83300 - 000

SANDIA NATIONAL LABORATORIES (NM)

ENGLISH

PART CLASSIFICATION: UNCLASSIFIED

DRAWING CLASSIFICATION: UNCLASSIFIED

TITLE: LAUNCHER MOUNT ASSEMBLY

(3.000 BORE LAUNCHER)

SIZE: D | DRAWING NUMBER: R83300 | ISSUE: A

CAGE: 14213 | SCALE: 1:16 | SHEET 1 OF 8

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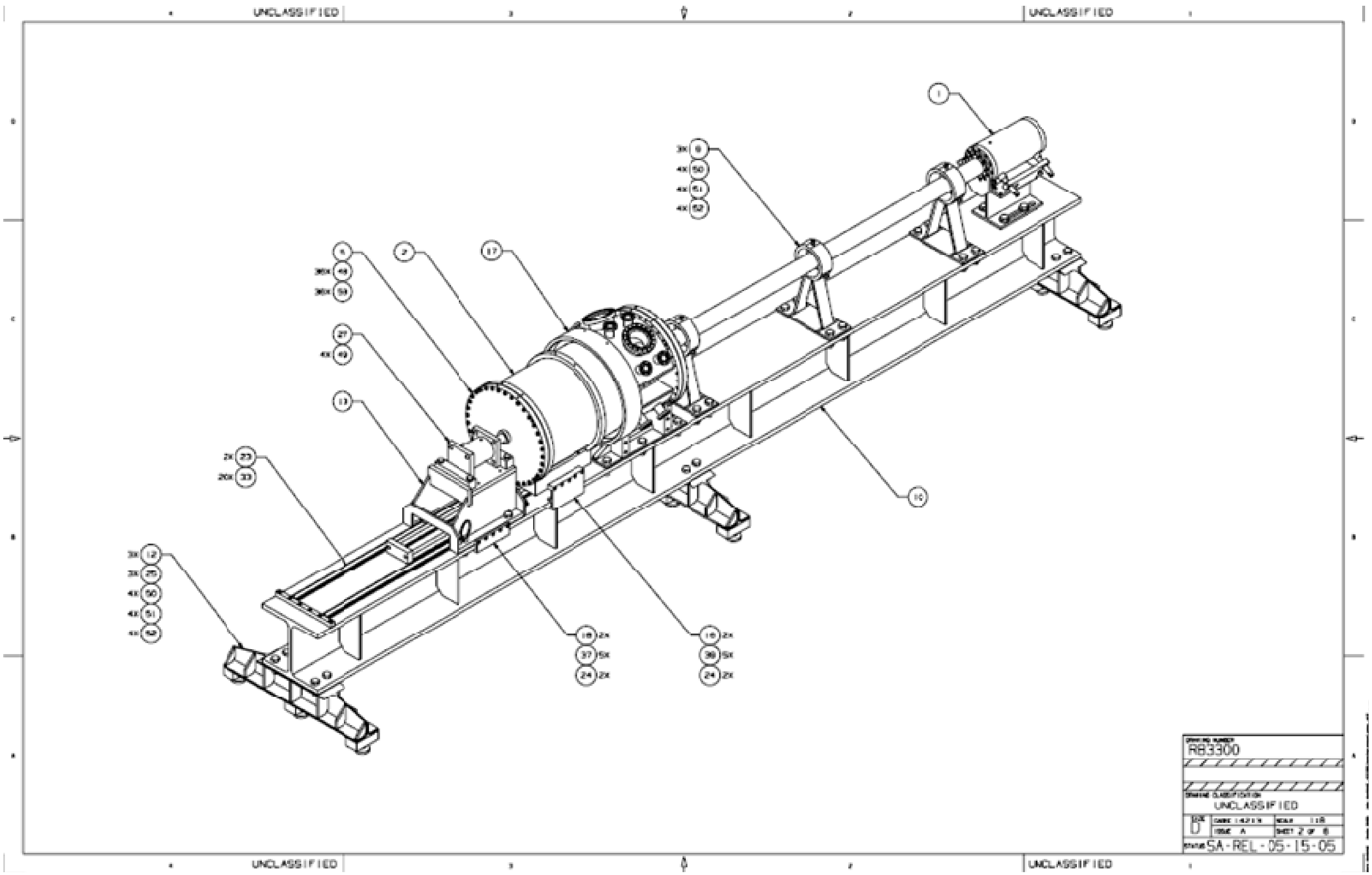
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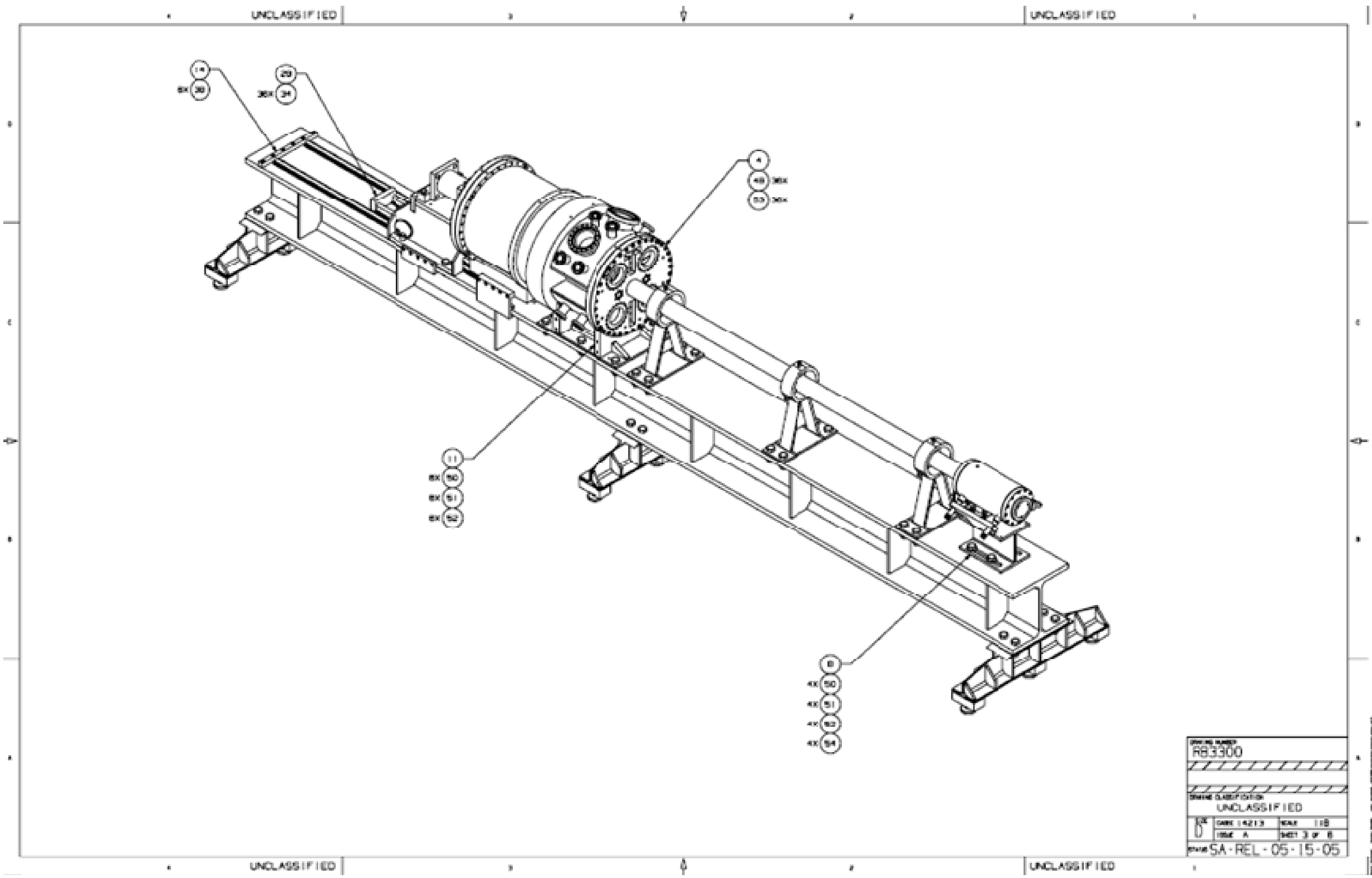

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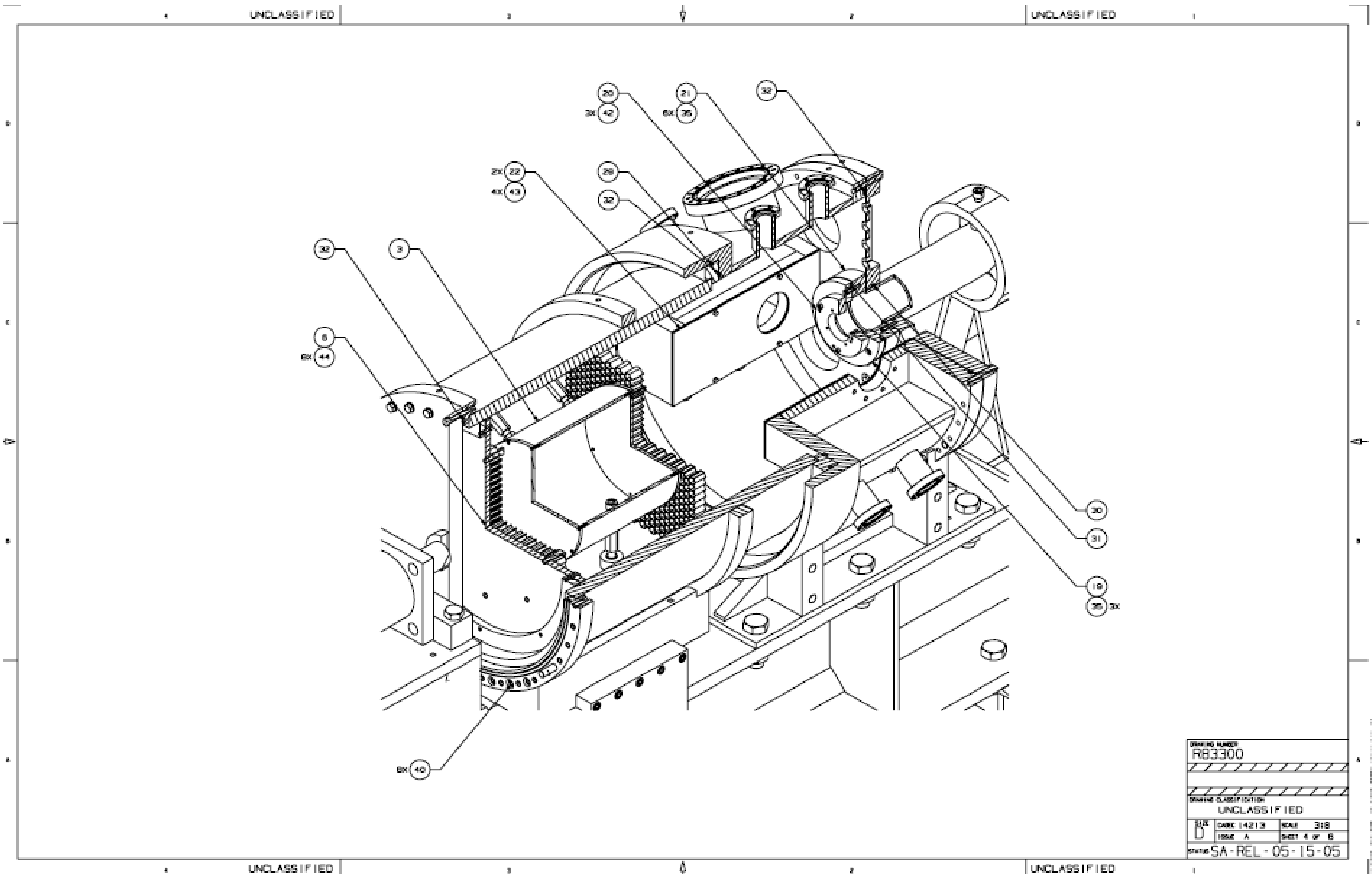
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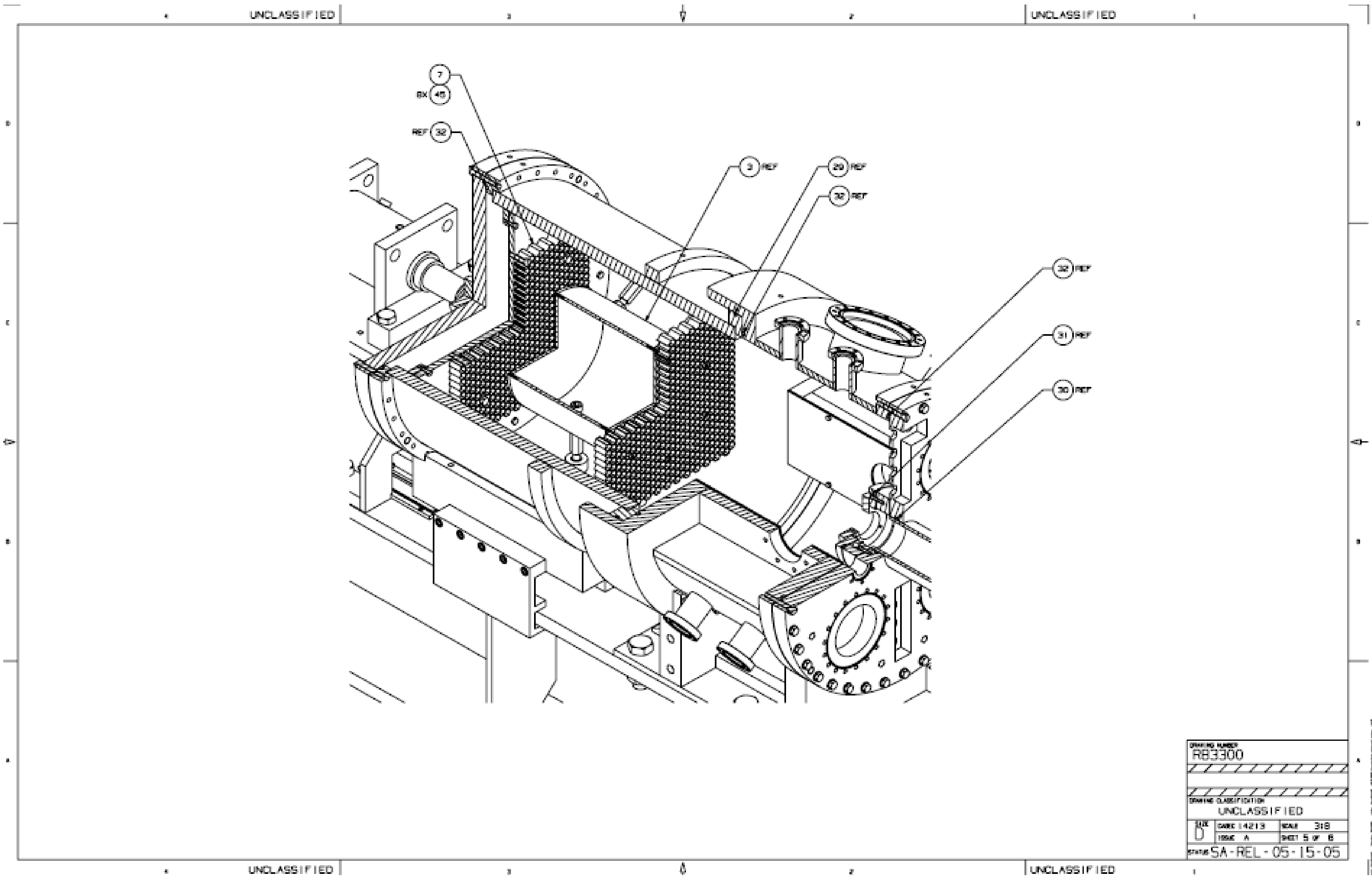
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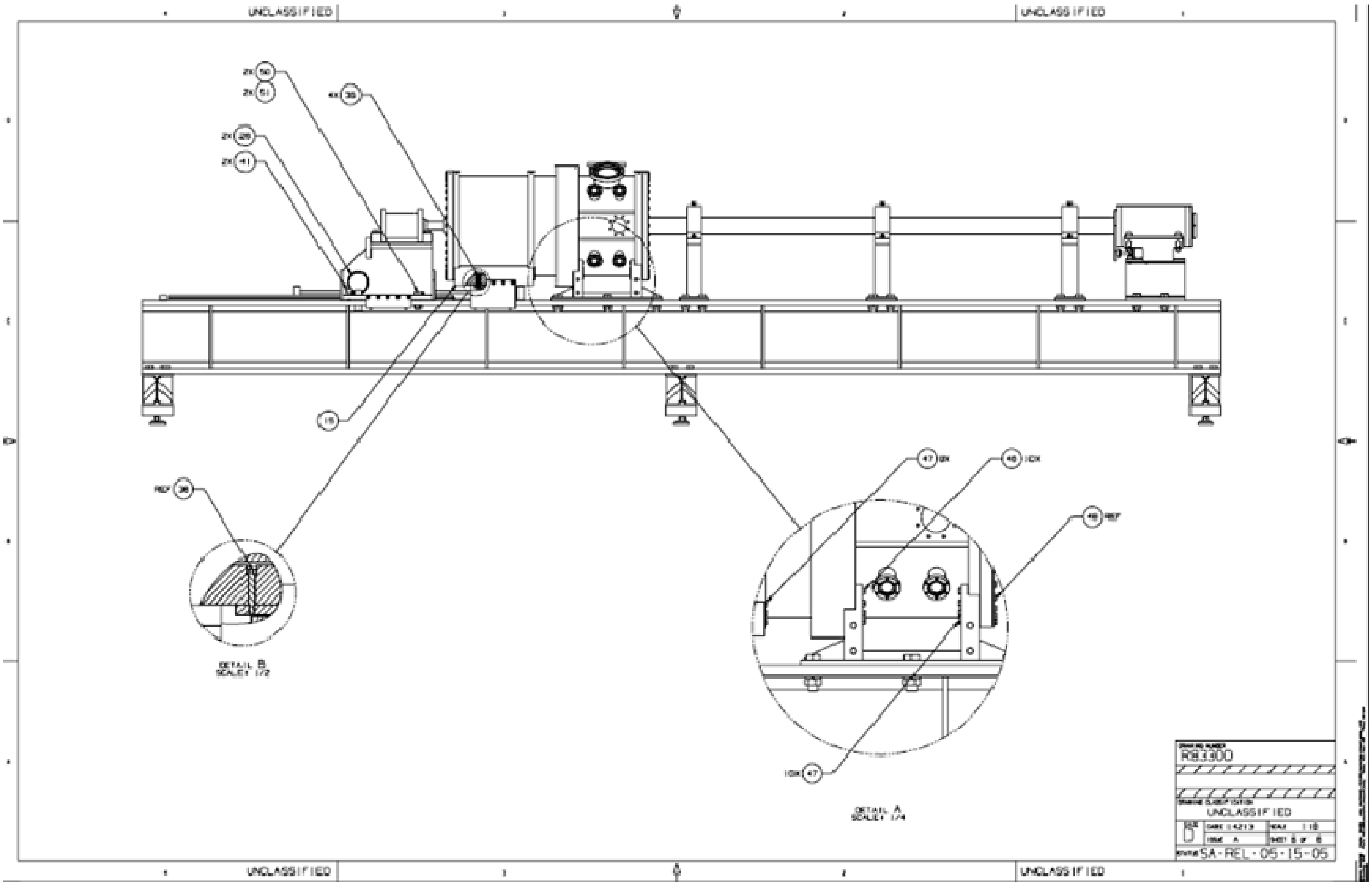
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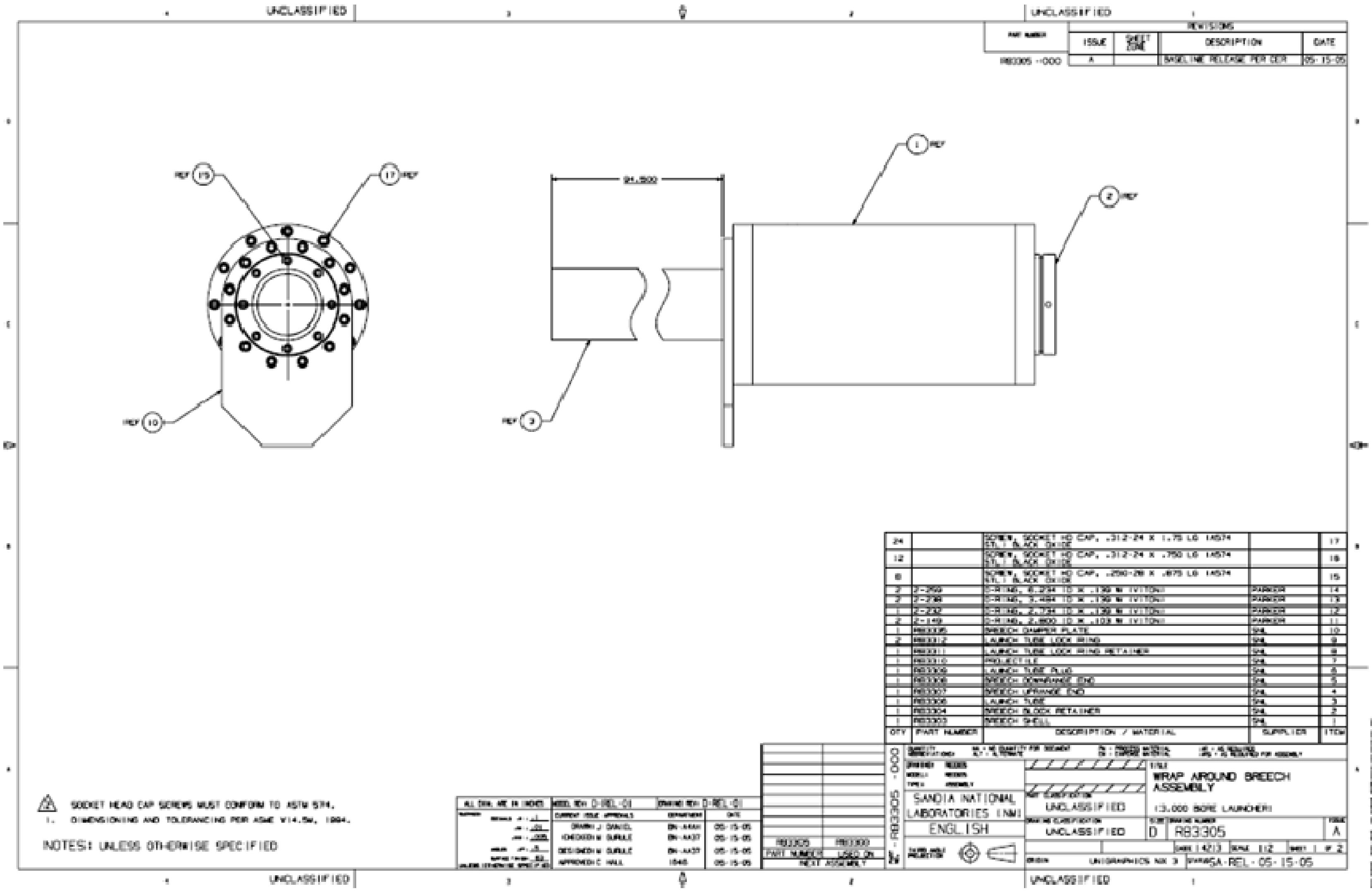
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REF 10
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2 REF
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SCREW, SOCKET HD CAP, .250-28 X .875 LG 14574 STL; BLACK OXIDE
O-RING, 6.234 ID X .139 W (VITON)
O-RING, 3.484 ID X .139 W (VITON)
O-RING, 2.734 ID X .139 W (VITON)
O-RING, 2.800 ID X .103 W (VITON)
BREECH DAMPER PLATE
LAUNCH TUBE LOCK RING
LAUNCH TUBE LOCK RING RETAINER
PROJECTILE
LAUNCH TUBE PLUG
BREECH DOWNRANGE END
BREECH UPRANGE END
LAUNCH TUBE
BREECH BLOCK RETAINER
BREECH SHELL
PARKER
SNL
QTY
PART NUMBER
DESCRIPTION / MATERIAL
SUPPLIER
ITEM
SOCKET HEAD CAP SCREWS MUST CONFORM TO ASTM 574.
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
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APPROVED C HALL
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UNCLASSIFIED
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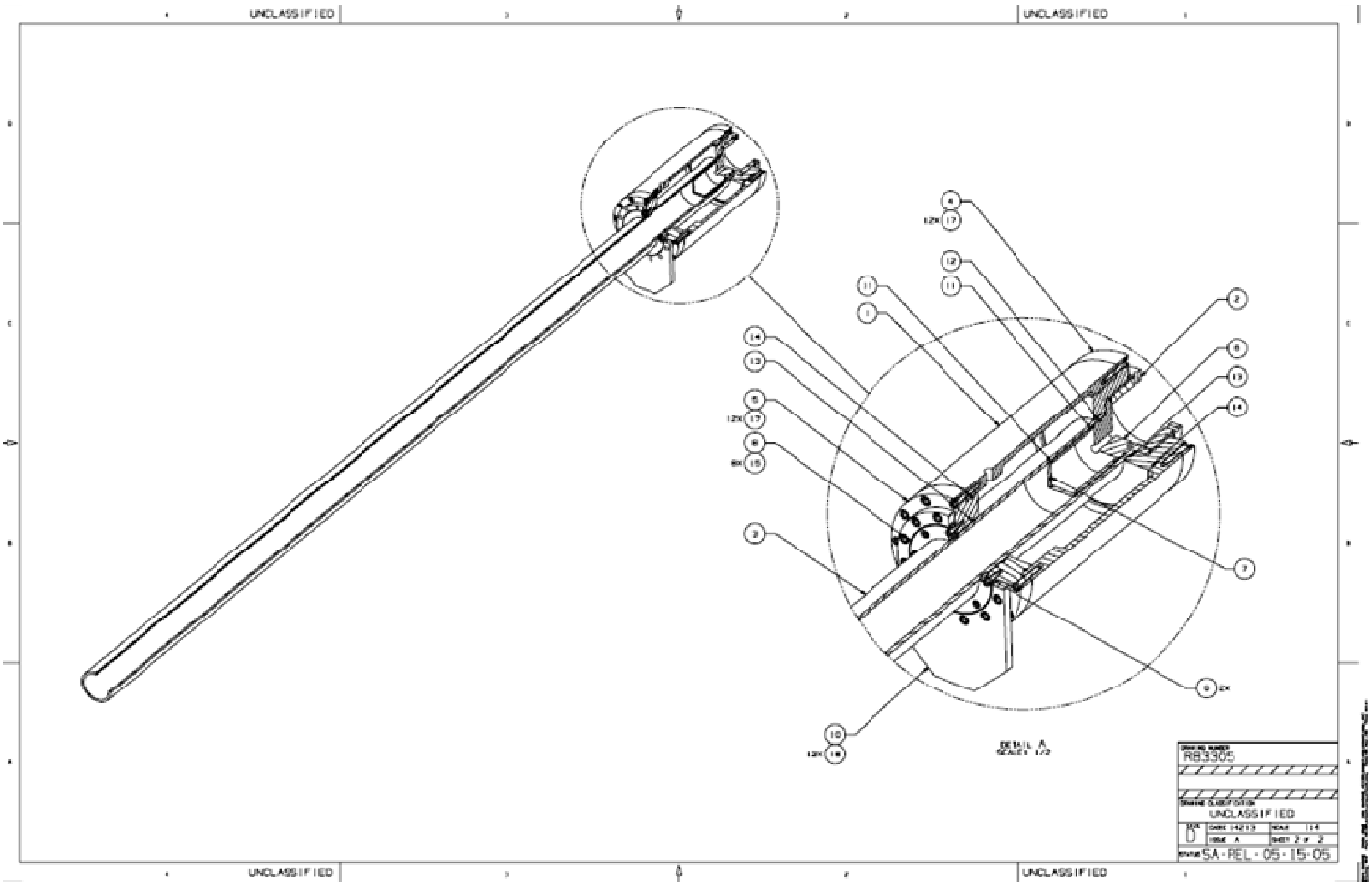
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APPENDIX B. GAS GUN INSTALLATION PROCEDURE

Installation Procedure is prepared with reference to APPENDIX A. ASSEMBLY DRAWINGS OF GAS GUN FROM SANDIA NATIONAL LABORATORIES.

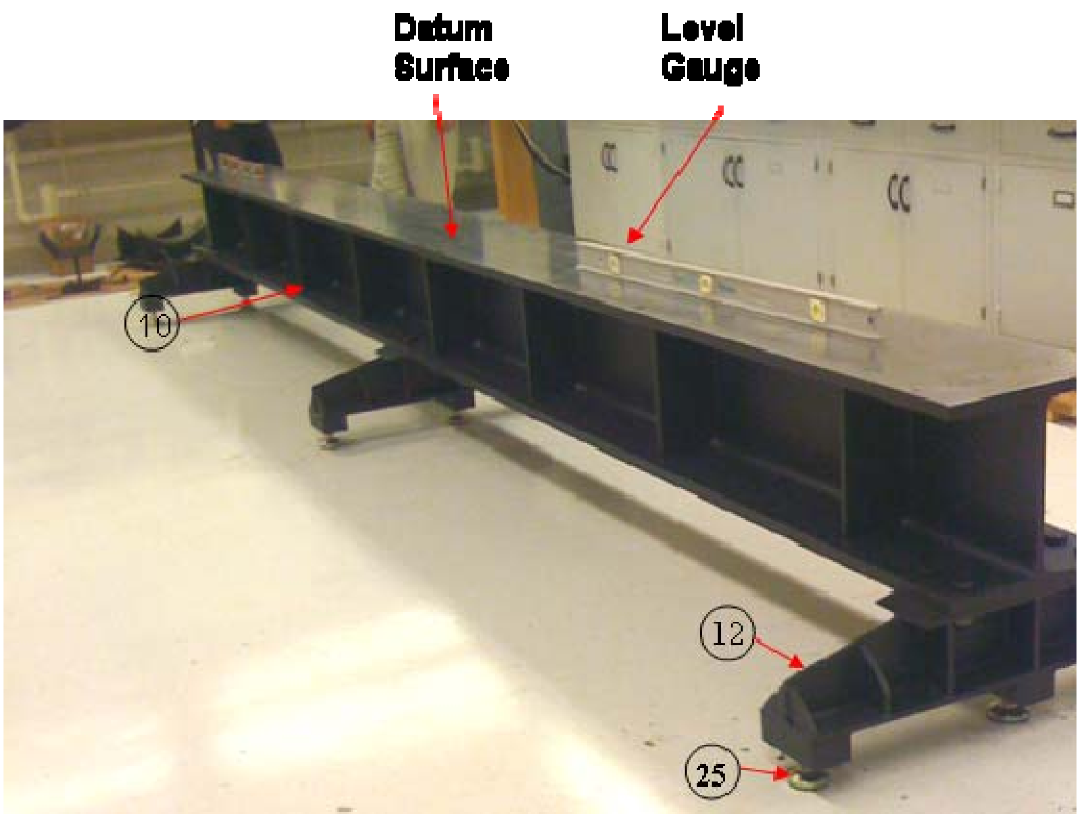
Part List of Launcher Mount Assembly

4		WASHER, FLAT, 1.00 (STL, HIGH STRENGTH) BLACK OXIDE		54
72		WASHER, FLAT, .375 (STL, HIGH STRENGTH) BLACK OXIDE		53
34		WASHER, SPLIT LOCK, 1.00 (STL, HIGH STRENGTH) BLACK OXIDE		52
36		NUT, HEX 1.00-8 (GRADE 8) HIGH STRENGTH		51
36		BOLT, HEX HD 1.00-8 X 3.00 LG (GRADE 8) HIGH STRENGTH		50
4		BOLT, HEX HD .750-16 X 3.00 LG (GRADE 8) HIGH STRENGTH		49
72		SCREW, HEX HD CAP, .375-24 X 2.25 LG (GRADE 8) HIGH STRENGTH		48
18		SCREW, HEX HD CAP, .375-24 X 1.75 LG (GRADE 8) HIGH STRENGTH		47
10		SCREW, HEX HD CAP, .375-24 X 1.25 LG (GRADE 8) HIGH STRENGTH		46
8		SCREW, HEX HD CAP, .375-16 X 1.50 LG (GRADE 8) HIGH STRENGTH		45
8		SCREW, HEX HD CAP, .250-20 X 1.00 LG (GRADE 8) HIGH STRENGTH		44
8		SCREW, HEX HD CAP, 10-32 X .50 LG (GRADE 8) HIGH STRENGTH		43
3		SCREW, SOCKET HD CAP, 10-32 X 1.00 LG (BRASS)		42
2		SCREW, SOCKET HD CAP, .750-10 X 1.50 LG (A574 STL) BLACK OXIDE		41
8		SCREW, SOCKET HD CAP, .375-24 X 1.25 LG (A574 STL) BLACK OXIDE		40
10		SCREW, SOCKET HD CAP, .375-16 X 1.50 LG (A574 STL) BLACK OXIDE		39
6		SCREW, SOCKET HD CAP, .375-16 X 1.25 LG (A574 STL) BLACK OXIDE		38
10		SCREW, SOCKET HD CAP, .375-16 X 1.00 LG (A574 STL) BLACK OXIDE		37
4		SCREW, SOCKET HD CAP, .312-18 X 2.00 LG (A574 STL) BLACK OXIDE		36
9		SCREW, SOCKET HD CAP, .250-20 X 1.00 LG (A574 STL) BLACK OXIDE		35
32		SCREW, SOCKET HD CAP, 10-32 X .875 LG (A574 STL) BLACK OXIDE		34
40		SCREW, SOCKET HD CAP, 8-32 X .750 LG (A574 STL) BLACK OXIDE		33
3	2-468	O-RING, 19.455 ID X .275 W (VITON)	PARKER	32
1	2-433	O-RING, 5.475 ID X .275 W (VITON)	PARKER	31
1	2-341	O-RING, 3.475 ID X .210 W (VITON)	PARKER	30
1	2-391	O-RING, 21.955 ID X .210 W (VITON)	PARKER	29
1	4A-12-T-SS-T36	LINEAR MOTION STAGE	SMI	28
1	HDIA1 3.0 X 2	SHOCK ABSORBER, HDIA1 SERIES 3.0 X 2	ENIDINE	27
2	95165A510	QUICK RELEASE PIN, RING GRIP, 1.00 DIA	McMASTER CARR	26
9	6111K86	LEVELING FOOT	McMASTER CARR	25
8	3408A84	SPRING PLUNGER	McMASTER CARR	24
2	R83377	SHOCK ABSORBER MOUNT RAIL	SNL	23
2	R83375	DIAGNOSTIC TANK SIDE BLAST SHIELD	SNL	22
1	R83370	TARGET PLATE MOUNT EXTENSION	SNL	21
1	R83367	TARGET PLATE	SNL	20
1	R83366	TARGET PLATE MOUNT	SNL	19
2	R83365	SHOCK ABSORBER MOUNT SIDE SUPPORT	SNL	18
1	R83356	DIAGNOSTIC TANK ASSEMBLY	SNL	17
2	R83355	CATCHER TANK CRADLE SIDE SUPPORT	SNL	16
1	R83354	CATCHER TANK CRADLE	SNL	15
1	R83353	SHOCK ABSORBER MOUNT STOP BAR	SNL	14
1	R83347	SHOCK ABSORBER MOUNT ASSEMBLY	SNL	13
3	R83344	MAIN RAIL MOUNT SUPPORT FOOT	SNL	12
1	R83338	DIAGNOSTIC TANK MOUNT ASSEMBLY	SNL	11
1	R83336	MAIN RAIL MOUNT	SNL	10
3	R83331	LAUNCH TUBE SUPPORT ASSEMBLY	SNL	9
1	R83328	BREECH SUPPORT ASSEMBLY	SNL	8
1	R83318	HONEYCOMB ENERGY ABSORBER	SNL	7
1	R83317	CATCHER TANK BLAST SHIELD	SNL	6
1	R83316	CATCHER TANK END PLATE	SNL	5
1	R83315	DIAGNOSTIC TANK FRONT PLATE	SNL	4
1	R83314	SLIDING BAFFLE ASSEMBLY	SNL	3
1	R83313	CATCHER TANK ASSEMBLY	SNL	2
1	R83305	WRAP AROUND BREECH ASSEMBLY	SNL	1
QTY	PART NUMBER	DESCRIPTION / MATERIAL	SUPPLIER	ITEM

1. Step 1

Assemble:

- Main Rail Mount, Item 10
- Main Rail Mount Support Foot (x 3), Item 12
- Leveling Foot (x 9), Item 25
- 1.00-8 x 3” Bolt (x12), Item 50
- 1.00-8 x 3” Nut (x12), Item 51
- 1.00” Washer, Split Lock (x12), Item 52

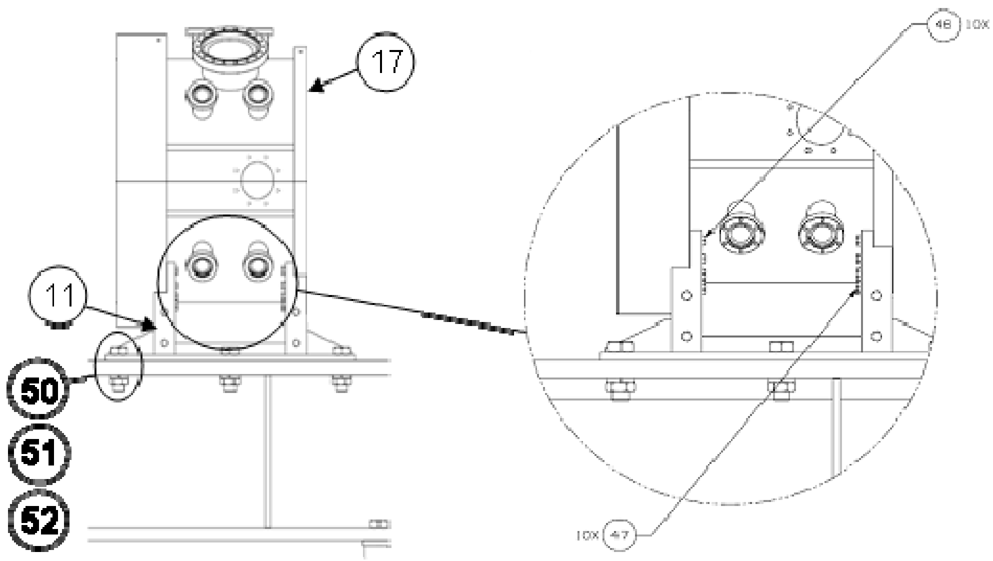


- Torque 1.00” fasteners to 700 ft-lbs
- Adjust horizontal datum surface to be flat with reference to the floor, using level gauge.

2. Step 2

Assemble:

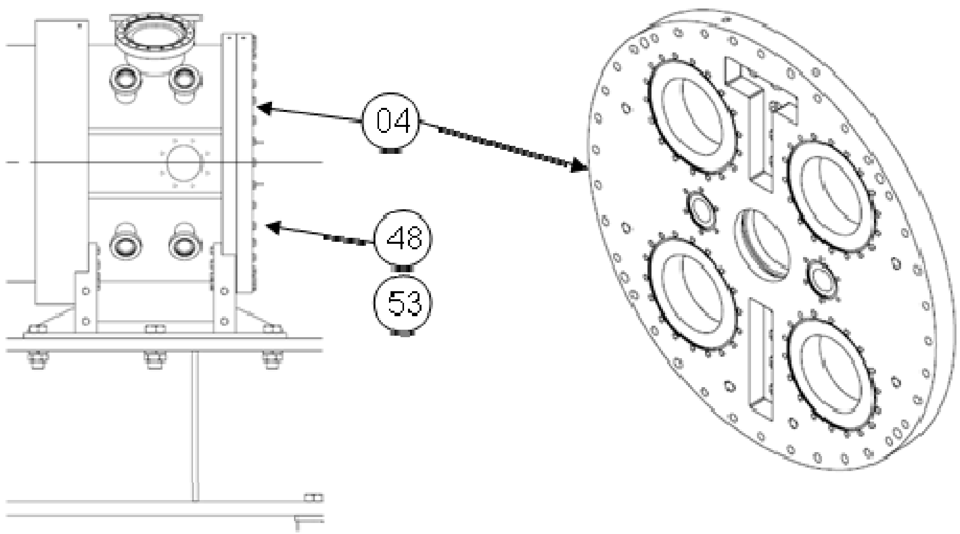
- Diagnostic Tank Assembly, Item 17
- Diagnostic Tank Mount Assembly, Item 11
- 1.00-8 x 3” Bolt (x6), Item 50
- 1.00-8 x 3” Nut (x6), Item 51
- 1.00” Washer, Split Lock (x6), Item 52
- Do not tighten 1.00” Fasteners. Tighten only after alignment with interfacing parts (Torque 1.00” fasteners to 700ft-lbs)
- 0.375-24 x 1.25” Hex Hd Cap Screw (x10), Item 46
- 0.375-24 x 1.75” Hex Hd Cap Screw (x10), Item 47
- Torque 0.375” fasteners to 41 ft-lbs



3. Step 3

Install:

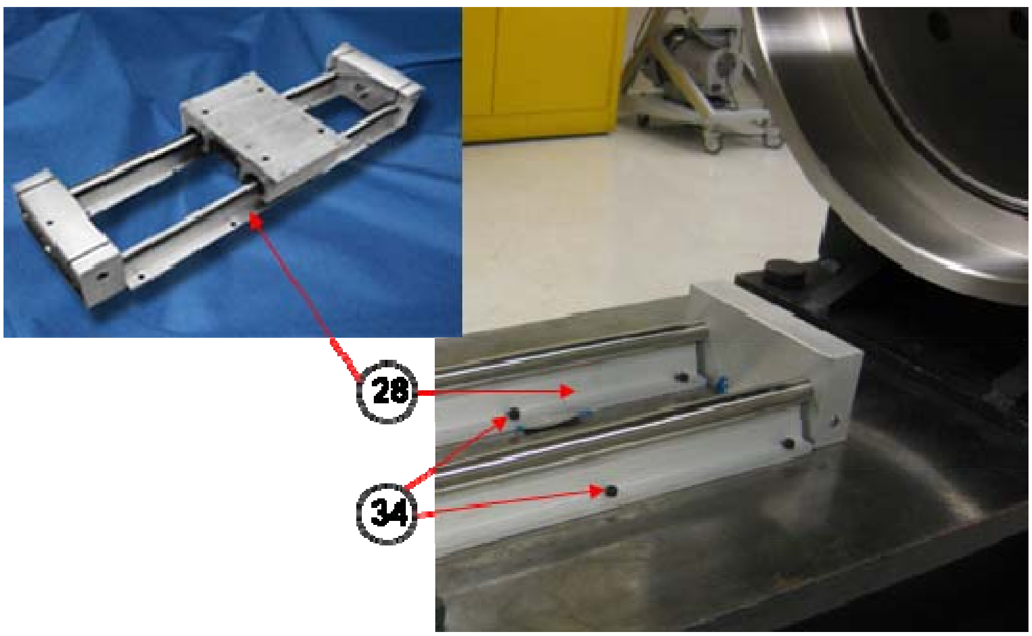
- Diagnostic Tank Front Plate, Item 4
- O-Ring, 19.455 ID x 0.275 W (Viton), Item 32
- O-Ring, between Interface of Diagnostic Tank Front Plate and Diagnostic Tank Assembly
- 0.375-24 x 2.25” Hex Hd Cap Screw (x36), Item 48
- 0.375” Washer Flat (x36), Item 53
- Torque 0.375” fasteners to 41 ft-lbs



4. **Step 4**

Install:

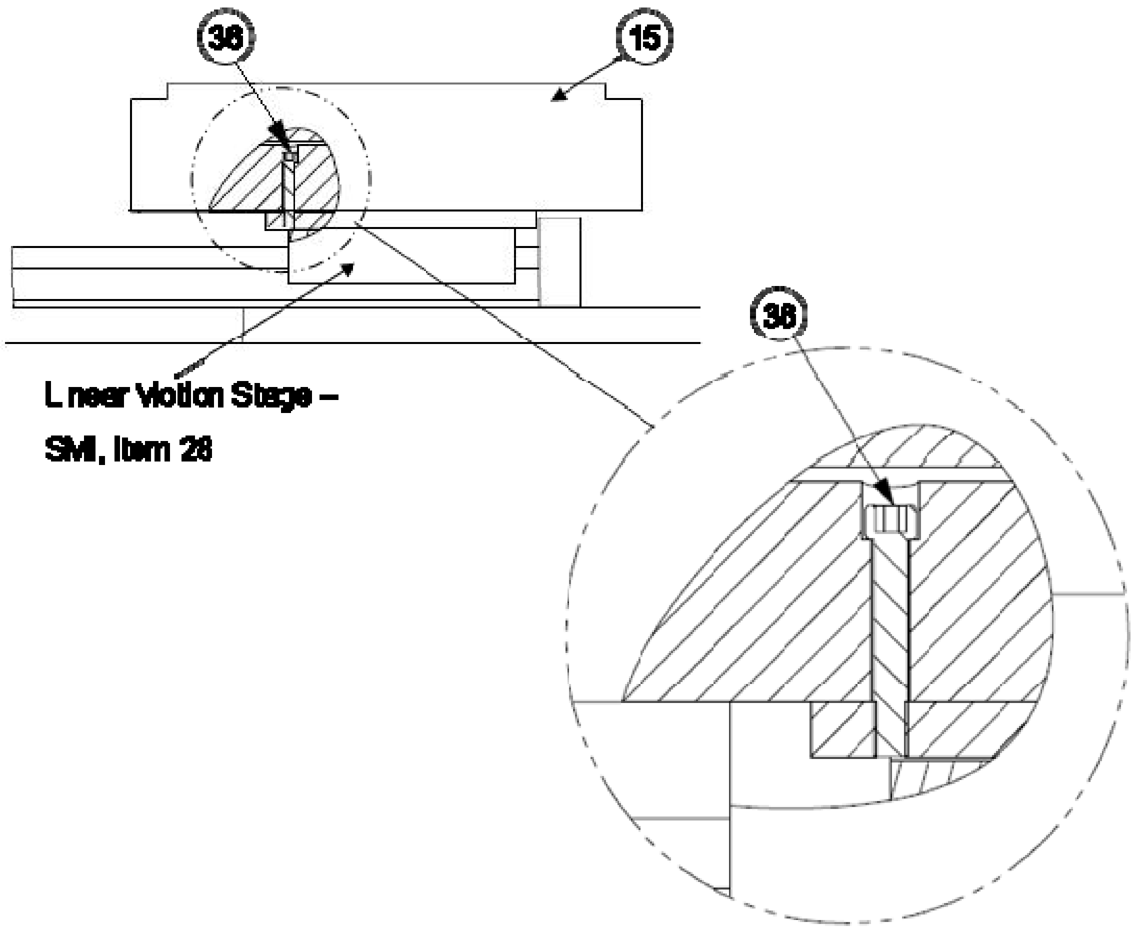
- Linear Motion Stage - SMI, Item 28
- 0.3125 x 0.875” Socket Hd Cap Screw (x36), Item 34
- Do not tighten 0.3125 x 0.875” Socket Hd Cap Screw. Tighten only after alignment with interfacing parts (Torque 0.3125” fasteners to 23 ft-lbs)



5. Step 5

Install:

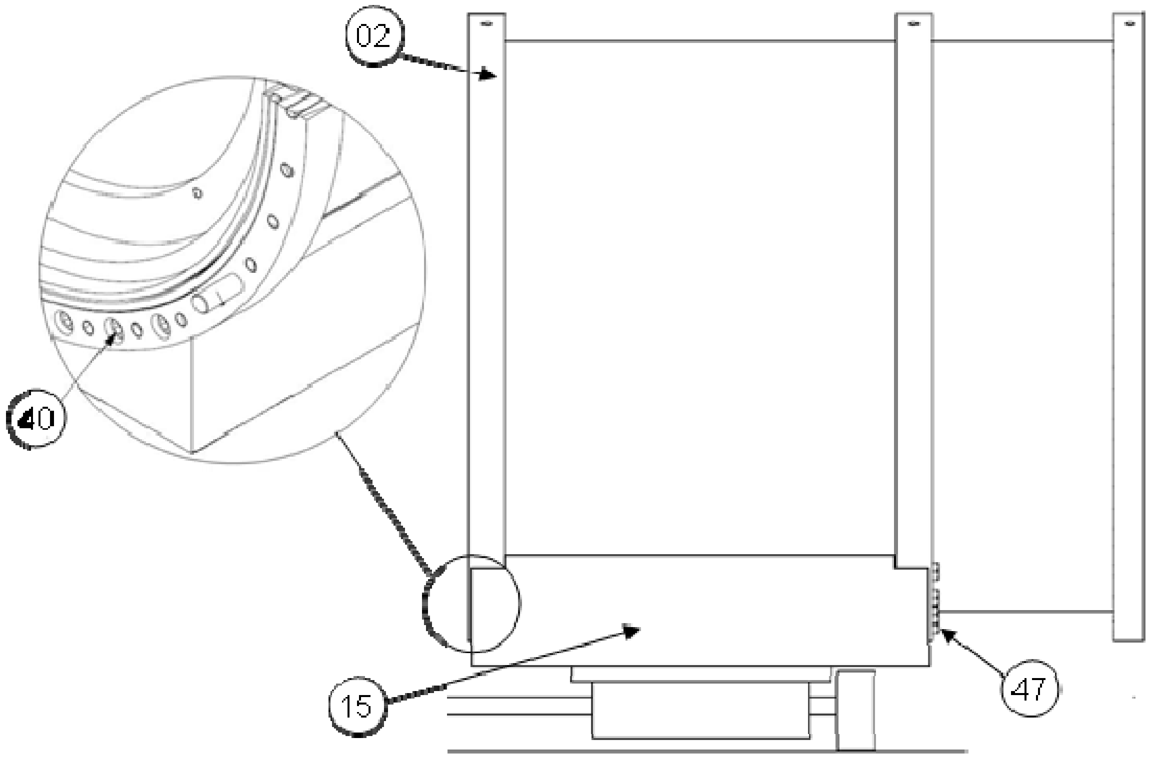
- Catcher Tank Cradle, Item 15
- 0.312-18 x 2.00” Socket Hd Cap Screw (x4), Item 36
- Do not tighten 0.3125-18 x 2.00” Socket Hd Cap Screw. Tighten only after alignment of Catcher Tank Assembly and Diagnostic Tank Assembly. (Torque 0.3125” fasteners to 23 ft-lbs)



6. Step 6

Install:

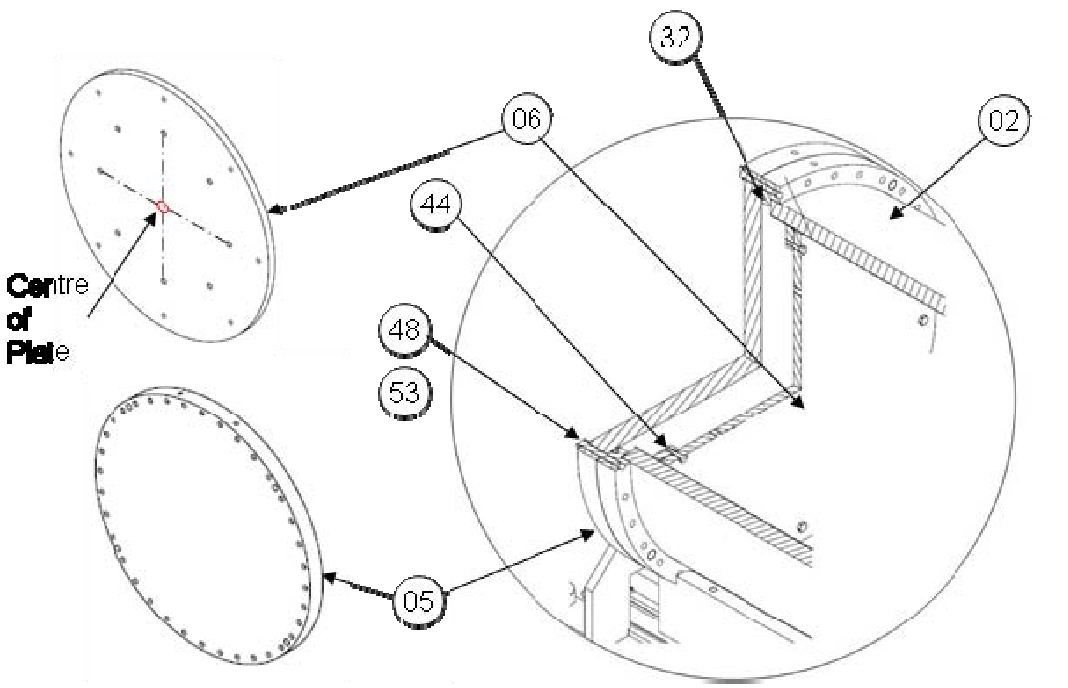
- Catcher Tank Assembly, Item 2
- 0.375-24 x 1.25” Socket Hd Cap Screw (x 8), Item 40
- 0.375-24 x 1.25” Hex Hd Cap Screw (x 8), Item 47
- Do not tighten 0.375-24 x 1.75” Socket Hd Cap Screw. Tighten only after alignment of Catcher Tank Assembly and Diagnostic Tank Assembly. (Torque 0.375” fasteners to 41 ft-lbs)



7. Step 7

Install:

- Catcher Tank End Plate, Item 5
- O-Ring, 19.455 ID x 0.275 W (Viton), Item 32
- O-Ring, between Interface of Catcher Tank End Plate and Catcher Tank Assembly
- 0.375-24 x 2.25” Hex Hd Cap Screw (x 36), Item 48
- 0.375” Washer Flat (x36), Item 53
- Torque 0.375” fasteners to 41 ft-lbs
- Catcher Tank Blast Shield, Item 6
- Locate and mark the centre of the plate, to be use for alignment.
- 0.250-20 x 1.00” Hex Hd Cap Screw (x 8), Item 44
- Torque 0.250” fasteners to 11 ft-lbs



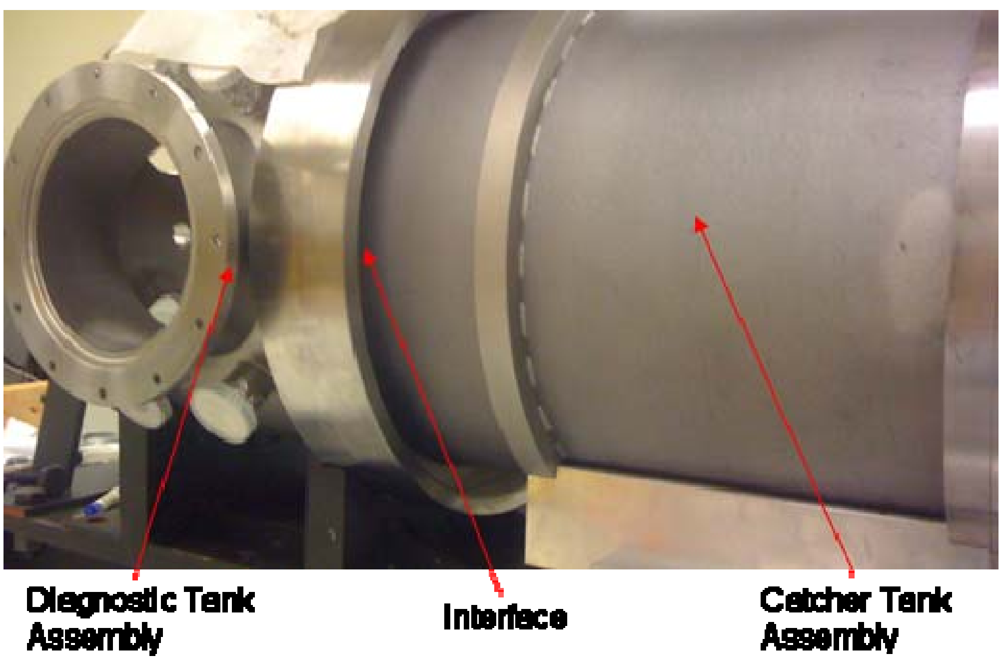
8. Step 8

Install:

- O-Ring, 19.455 ID x 0.275 W (Viton), Item 32, onto the Diagnostic Tank Assembly at the interface of Diagnostic Tank Assembly and Catcher Tank Assembly
- O-Ring, 21.955 ID x 0.210 W (Viton), Item 29, onto the Catcher Tank Assembly at the interface of Diagnostic Tank Assembly and Catcher Tank Assembly

9. Step 9

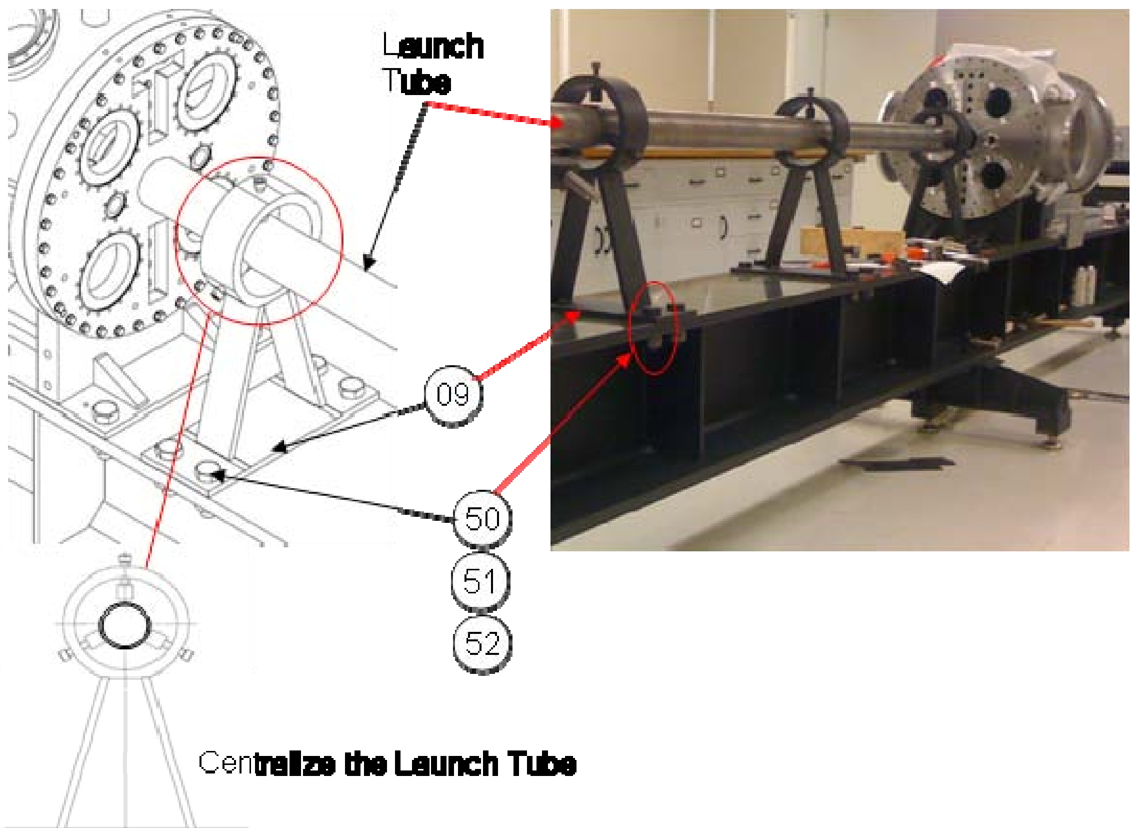
- Translate the catcher tank assembly to couple to the diagnostic tank assembly.
- Alignment is required to couple the diagnostic tank assembly and the catcher tank assembly. Ensure the both the O-Rings at the interface are evenly compressed.



10. Step 10

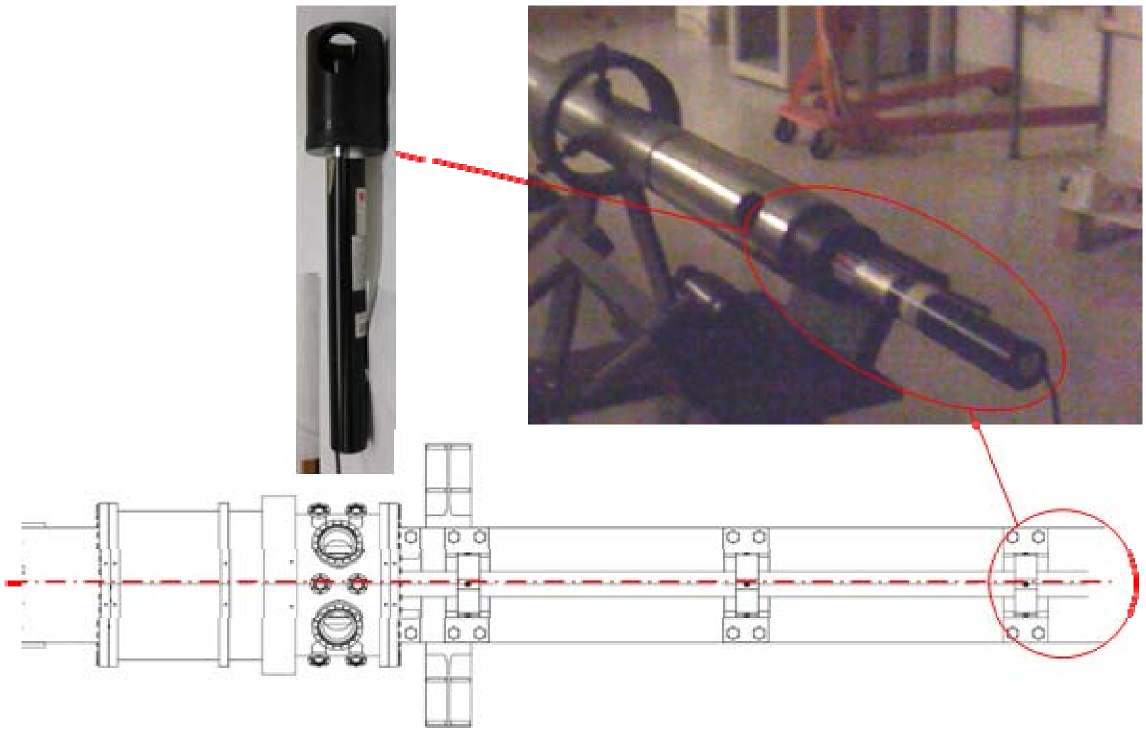
Install:

- Launch Tube Support Assembly (x3), Item 9
- 1.00-8 x 3" Bolt (x12), Item 50
- 1.00-8 x 3" Nut (x12), Item 51
- 1.00" Washer, Split Lock (x12), Item 52
- Do not tighten 1.00" Fasteners. Tighten only after alignment with interfacing parts (Torque 1.00" fasteners to 700ft-lbs)
- O-Ring, 3.475 ID x 0.210 W (Viton), Item 30, onto the interface between Diagnostic Tank Front Plate and Launch Tube
- Insert Launch Tube into the Diagnostic Tank Front Plate.

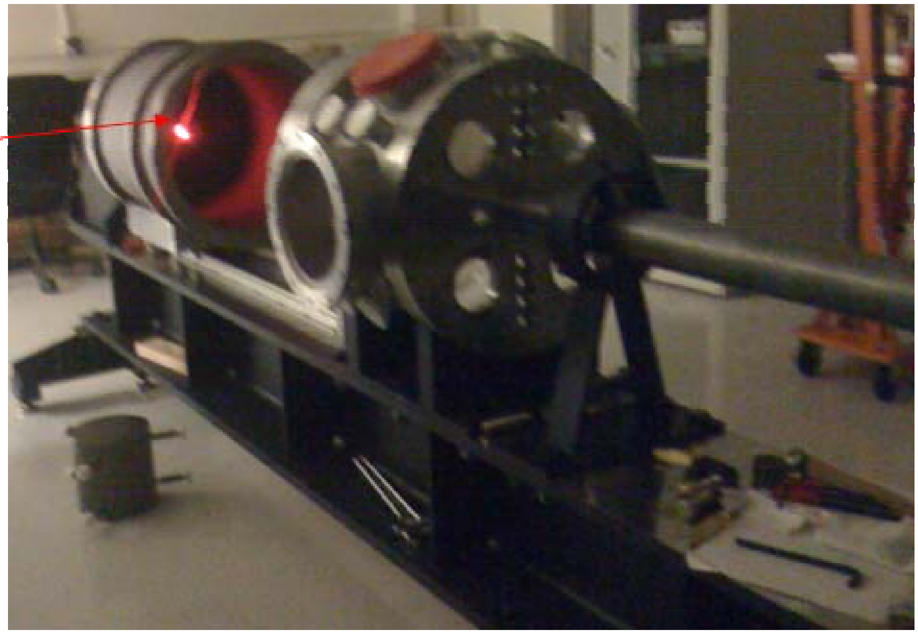


11. Step 11 – System Alignment

- Insert Alignment Adaptor (AA) into Launch Tube.
- Insert Laser Alignment Tool (LAT) into the Adaptor.
- Ensure that the Diagnostic Tank Assembly and Catcher Tank Assembly are coupled before alignment.



- To ensure that the AA and LAT is centered, mark on the Catcher Tank Blast Shield where the laser is pointing. Then rotate AA and LAT by 180 degrees. Ensure that the laser is pointing at the same marked point; if not shims are required to centralize the AA and LAT. Then rotate AA and LAT by 180 degrees to confirm. (REMOVE LAT ONLY AFTER FINAL ALIGNMENT)
- To align the sub-systems, ensure that the laser points onto the center marked on the Catcher Tank Blast Shield.

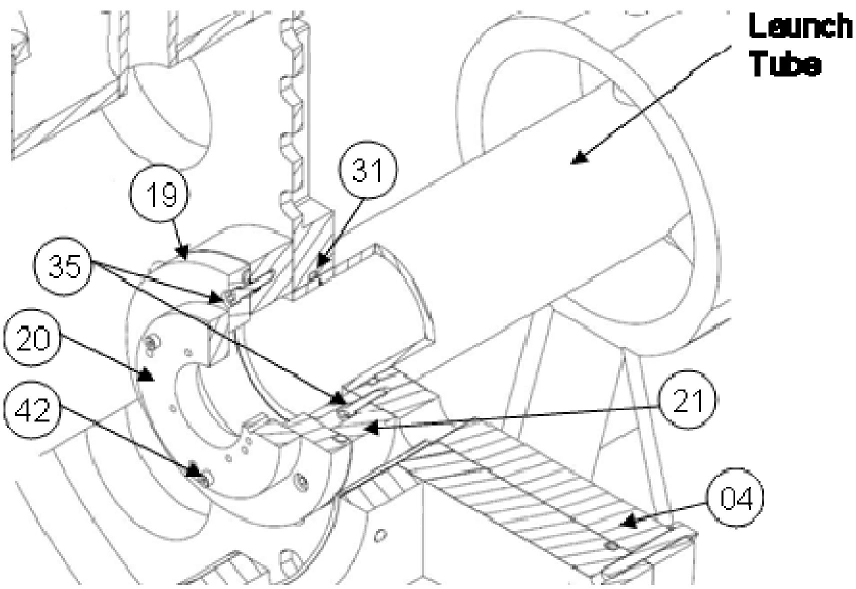


- Tighten the fasteners of the Diagnostic Tank Mount Assembly.
- De-couple the Diagnostic Tank Assembly from the Catcher Tank Assembly. Position the Catcher Tank Assembly to the end of the Linear Motion Stage - SMI, Item 28.
- Check that the laser points to the centermarked on the Catcher Tank Blast Shield.
- Couple the Diagnostic Tank Assembly from the Catcher Tank Assembly.
- Tighten the all Fasteners mentioned starting from steps 2, 4, 5, 6 and 10.

12. Step 12 – Alignment of Launch Tube to Target Plate

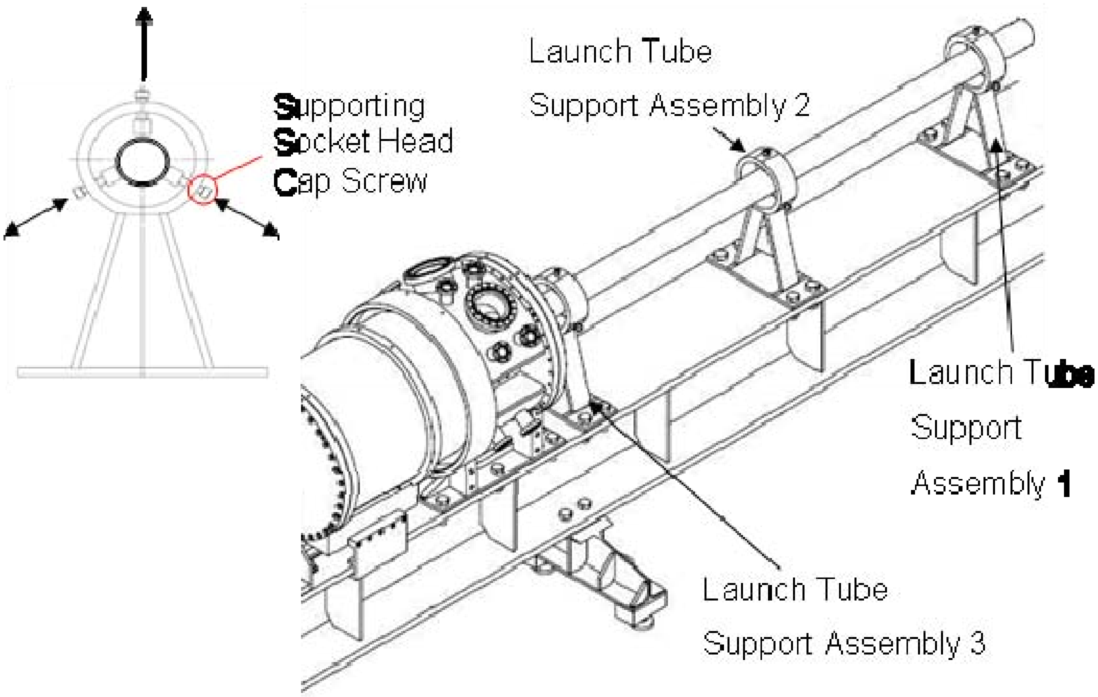
Install:

- Target Plate Mount Extension, Item 21
- Target Plate Mount, Item 19
- O-Ring, 5.475 ID x 0.275 W (Viton), Item 31, onto the Target Mount Plate
- 0.250-20 x 1.00” Socket Hd Cap Screw (x 12), Item 35
- Torque 0.250” fasteners to 11 ft-lbs
- Target Plate, Item 20 (To be made with Mirror on side facing Launch Tube)
- 0.312 x 1.00” Socket Hd Cap Screw (x 3), Item 42



- To align the Target Plate to the Launch Tube, shine the laser onto Target Plate and observe the reflection of the laser on the front face of the LAT.

- For the Target Plate to be aligned to the Launch Tube, the reflected laser beam must be within a radius of 0.106” from the center of the surface of LAT.
- To align the reflected laser to the required position:

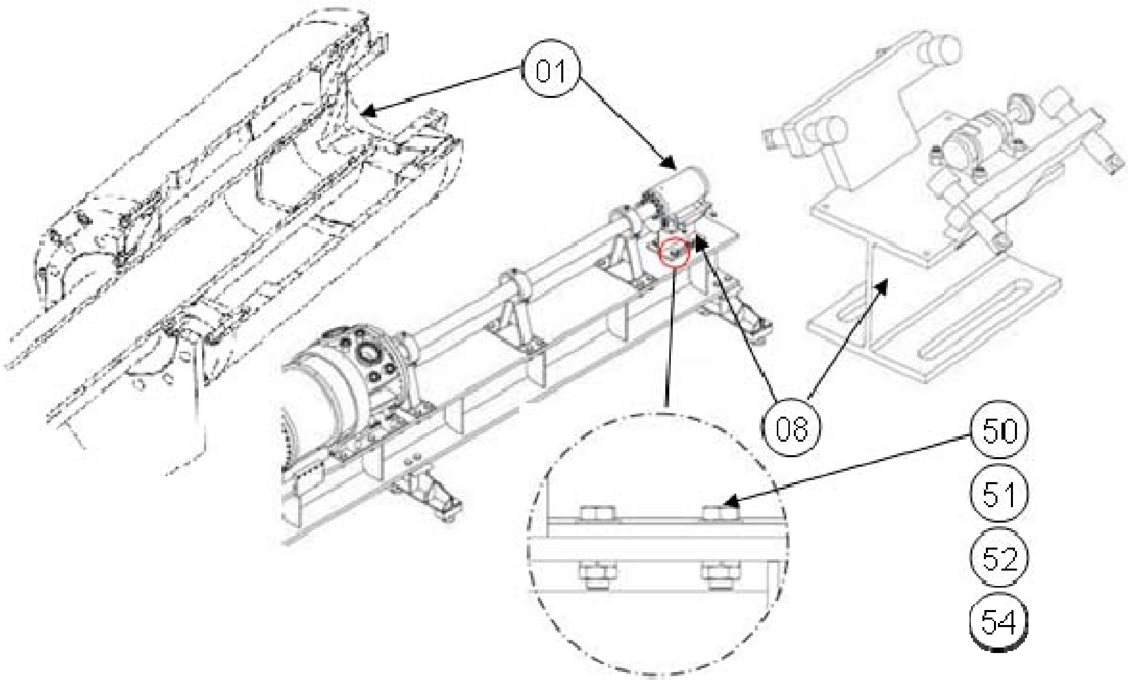


- Release all supporting screws on Launch Tube Support Assembly 2.
- Release the top supporting screw of the Launch Tube Support Assembly 1 and 3. (The weight of the Launch Tube is still supported by the bottom 2 supporting screws)
- Adjust the bottom 2 supporting screws of Launch Tube Support Assembly 1 to move the reflected laser to the required position.
- Secure all supporting screws once the reflected laser is shining onto the required position.
- Remove AA and LAT.

13. Step 13 – Breech and Breech Support Assembly

Install:

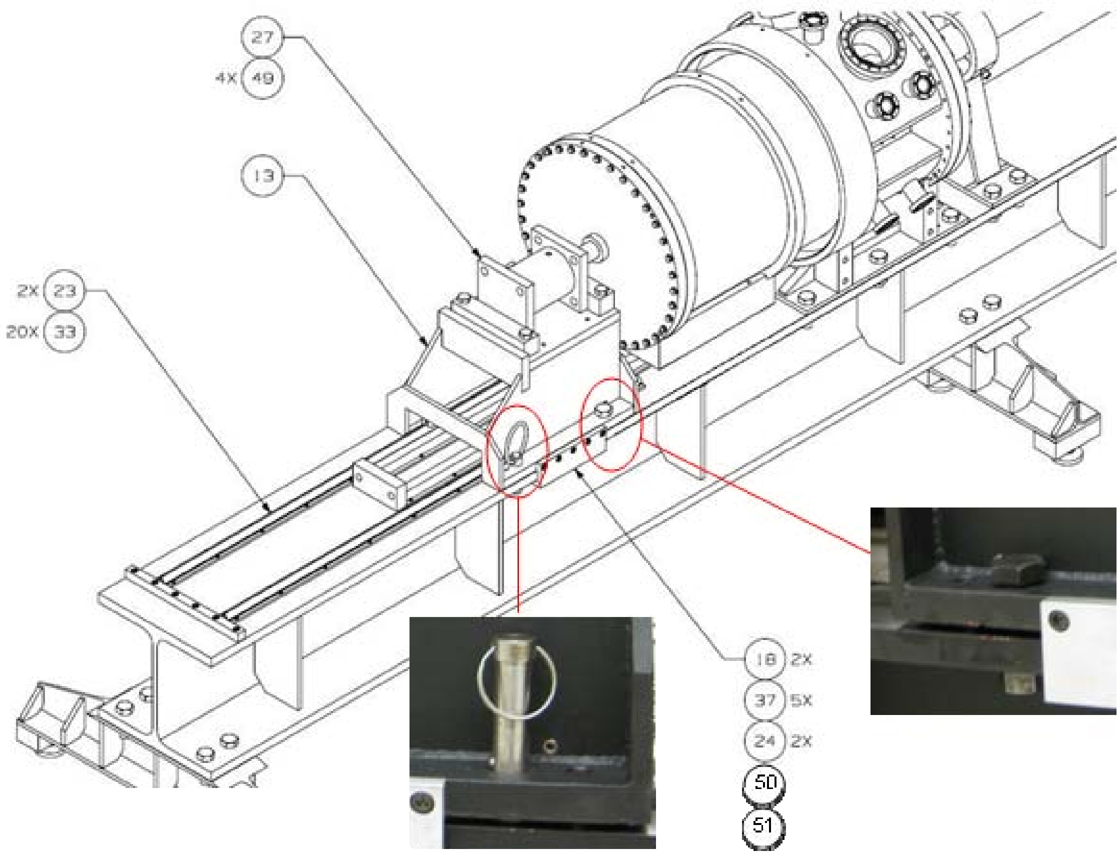
- Wrap Around Breech Assembly, Item 1
- Breech Support Assembly, Item 8
- 1.00-8 x 3” Bolt (x4), Item 50
- 1.00-8 x 3” Nut (x4), Item 51
- 1.00” Washer, Split Lock (x4), Item 52
- 1.00” Washer, Flat (x4), Item 54
- Torque 1.00” fasteners to 700 ft-lbs



14. Step 14 – Shock Absorber Mount Assembly

Install:

- Shock Absorber Mount Rail, Item 23
- 0.250 x 0.75” Socket Hd Cap Screw (x 20), Item 33
- Torque 0.250” fasteners to 11 ft-lbs
- Shock Absorber Mount Assembly, Item 13
- Shock Absorber, HD(A) Series 3.0 x 2, Item 27
- Shock Absorber Mount Side Support (x 2), Item 18
- 0.375-16 x 1.00” Socket Hd Cap Screw (x 10), Item 37

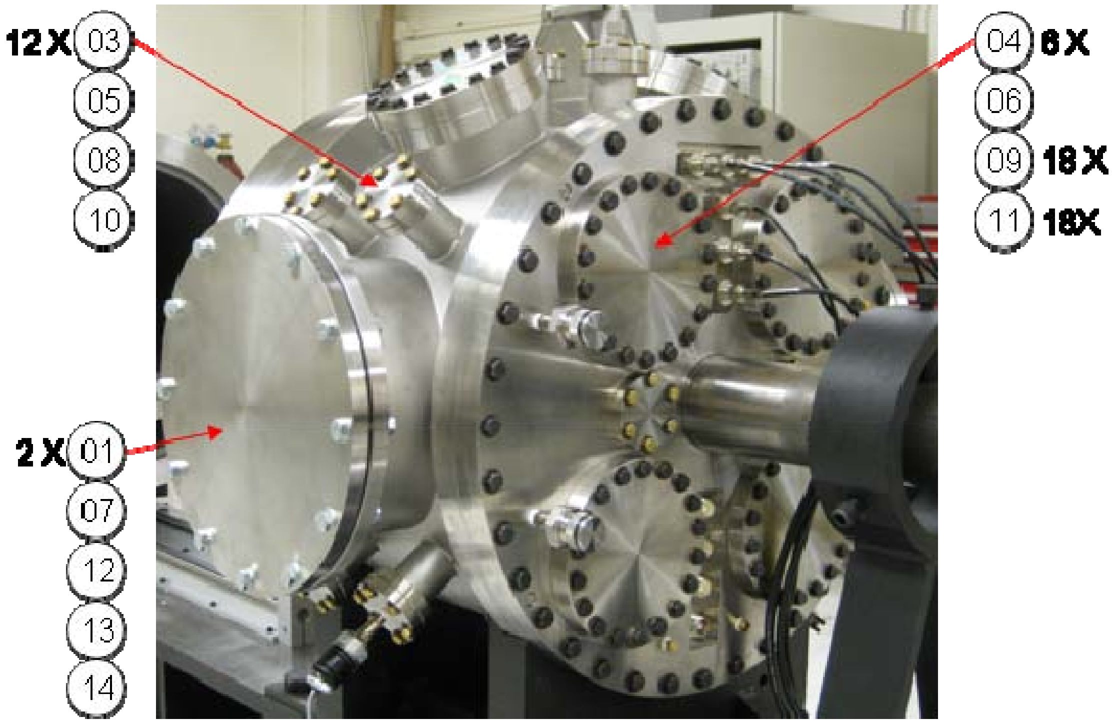


- Spring Plunger (x 2), Item 24
- 1.00-8 x 3” Bolt (x 2), Item 50
- 1.00-8 x 3” Nut (x 2), Item 51

15. Step 15 – Install Flanges of Diagnostic Tank Assembly

Install:

- CF Flange,2-3/4 OD, Non rotational, Blank (x 10), Item 3
- GASKET, COPPER , 1.45 ID (x 10), Item 5
- 0.250-28 x 0.875” Socket Hd Cap Screw (x 72), Item 8
- 0.250” Washer, Flat (x 72), Item 10
- Torque 0.250” fasteners to 11 ft-lbs
- CF Flange,6-3/4 OD, Non rotational, Blank (x 6), Item 4
- GASKET, COPPER , 5.01 ID (x 6), Item 6
- 0.312-24 x 1.250” Socket Hd Cap Screw (x 124), Item 9
- 0.312” Washer, Flat (x 124), Item 10
- Torque 0.250” fasteners to 23 ft-lbs
- BLANK OFF FLANGE (x 2), Item 1
- CENTERING RING (x 2), Item 7
- 0.375-16 x 2.00” Socket Hd Cap Screw (x 24), Item 12
- 0.375-16 Nut, Hex (x 24), Item 13
- 0.375” Washer, Flat (x 48), Item 14
- Torque 0.375” fasteners to 41 ft-lbs



QTY	PART NUMBER	DESCRIPTION/ MATERIAL	SUPPLIER	ITEM
48		WASHER, FLAT, .375 (STL, HIGH STRENGTH)		14
24		NUT, HEX .375-16 (GRADE 8) HIGH STRENGTH		13
24		SCREW, HEX HD CAP, .375-16 X2.00 LG (GRADE 8) HIGH STRENGTH		12
108		WASHER, FLAT, .312 (STL, HIGH STRENGTH) BLACK OXIDE		11
72		WASHER, FLAT, .250 (STL, HIGH STRENGTH) BLACK OXIDE		10

QTY	PART NUMBER	DESCRIPTION/ MATERIAL	SUPPLIER	ITEM
108		SCREW, HEX HD CAP, .312-24 X1.25 LG (GRADE 8) HIGH STRENGTH		9
72		SCREW, HEX HD CAP, .250-28 X .875 LG (GRADE 8) HIGH STRENGTH		8
2	#810014	CENTERING RING	MDC VACUUM	7
6	3095000	GASKET, COPPER , 5.01 ID	APPLIED VACUUM	6
12	3091500	GASKET, COPPER , 1.45 ID	APPLIED VACUUM	5
6	3015000	CF FLANGE, 6-3/4 OD,NON ROTATABLE, BLANK	APPLIED VACUUM	4
12	3011500	CF FLANGE, 2-3/4 OD,NON ROTATABLE, BLANK	APPLIED VACUUM	3
10	UG-1019A/U	CONNECTOR, HN(F) TO HN(F) ADAPTOR	TRU CONNECTOR CORP	2
2	#852004	BLANK OFF FLANGE	MDC VACUUM	1

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LIST OF REFERENCES

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